Computer aided seismic input selection for the new Italian seismic code

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(Received: April 20, 2009; accepted: July 27, 2009)

ABSTRACT The recently released Italian seismic code avails of the work of the Istituto Nazionale di Geofisica e Vulcanologia concerning the seismic hazard analysis of the Italian territory. This is reflected in the definition of seismic action on structures based on site-dependent elastic acceleration spectra closely approximating the uniform hazard spectra 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 non-linear structural analysis if appropriate tools are available to practitioners. The definition of the design spectra and the selection of ground motion suites according to the code are first reviewed here. Subsequently, a discusson how a specific software developed by the authors, REXEL, may help in finding record sets compatible with design spectra, is presented. Some illustrative examples are used factually to show how the new code and REXEL easily permit a rational record selection applied to earthquake engineering.

1. Introduction

When defining seismic action on structures, the new Italian building code, or NIBC (CS.LL.PP., 2008), overcomes the concept of seismic classification into zones of the national territory. In fact, previously the seismic actions of structures were defined by the OPCM 3274 (2003) and the OPCM 3431 (2005) on the basis of standard shapes of the elastic response spectrum, depending on the soil type classification and anchored to a reference value of the ground acceleration (a_g). This reference value was identified on the basis of the site of interest belonging to one of four possible seismic zones. The OPCM 3519 (2006) assumed the map MPS04 (http://zonesismiche.mi.ingv.it/), produced by Istituto Nazionale di Geofisica e Vulcanologia (INGV), as a reference for determining the a_g. In particular, it was recommended that a specific site in Zone I, II, III or IV be classified depending on the horizontal peak ground acceleration (PGA) on rock with a 10% probability of exceedance in 50 years [retrieved by means of probabilistic seismic hazard analysis or (PSHA)] falling in the intervals]0.25 g, 0.35 g],]0.15 g, 0.25g],]0.05 g, 0.15 g] and ≤ 0.05 g respectively. To each of these zones an a_g value equal to the upper limit of the interval was conservatively assigned. This had several consequences, first of all the code spectra were only indirectly related to the seismic hazard. In fact, for a site having a PGA value close to the lower bound of the interval of interest, the corresponding a_g value overestimated the PGA percentile derived by PSHA by about 0.1 g. Moreover, the classification of the municipalities into four seismic zones implied constant seismic hazard inside wide areas, often causing neighboring territories (with values of PGA that differ by only a few hundredths of

g) to be assigned to different seismic zones (with values of a_g differing by 0.1 g) as a result of the shape of the administrative boundaries rather than for an actual difference in the estimated seismic hazard. To mitigate this effect, both the OPCM 3274 (2003)and the OPCM 3519 (2006) allowed tolerance bounds in order to enable the regions to adjust around the thresholds of the four zones, but they were rarely used.

Currently the NIBC adopts the seismic hazard estimates of the INGV developed in the framework of the 2004-2006 agreement between INGV and the Italian Dipartimento della Protezione Civile (DPC) through a specific project (Progetto S1, http://esse1.mi.ingv.it) (Montaldo *et al*., 2007). The S1 project carried out PSHA (on rock) and PGA hazard disaggregation for each node of a regular grid having a 5 km spacing and covering the whole Italian territory with over 16,000 nodes. In particular, the results of the project include hazard curves in terms of spectral acceleration, *Sa(T)*, on rock, based on 9 return periods (T_R, ranging from 30 to 2475 years), for 11 vibration periods of a linear single degree of freedom system (T, ranging from 0 s to 2 s) of engineering interest. All data can be accessed and plotted on an interactive map at http://esse1-gis.mi.ingv.it.

The NIBC allows one to carry out design by considering response spectra derived from the INGV probabilistic seismic hazard analysis which is technically coincident with the uniform hazard spectum (UHS). As it will be shown, the detailed hazard information available allows to consider, for engineering purposes, the values of the seismic action better representing the hazard at the site, the nominal life, and the use of the structure. This is also reflected in the selection of ground motions for non-linear dynamic analysis.

In this paper, the prescriptions of the NIBC regarding record selection are briefly reviewed, and then a tool for computer-aided, code-based real record selection is presented. REXEL, which is available on the website of the Rete dei Laboratori Universitari di Ingegneria Sismica (ReLUIS, http://www.reluis.it/), allows one to define the design spectra according[1] to the NIBC for any site in Italy and to search for sets of 7 records compatible with them in an average sense.

Some illustrative examples show how the new code and REXEL, easily permit a rational record selection for code-based earthquake engineering applications.

2. Seismic action and reference spectra according to the NIBC

In section 3.2 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, P_{V_R}, to be exceeded in a reference period V_R (for example, many codes consider the probability of 10% in 50 years as a reference for structural design). 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 of the coefficient depends on the severity of losses

[1] REXEL also allows one to define spectra according to Eurocode 8 (CEN, 2003), or completely user-defined [see Iervolino *et al*. (2009) for details].

Table 1 - Possible values for P_{V_R}, C_U and V_N.

P_{VS} (Limit State)	***C_U***	***V_N***
81% - Operability	0.7 - Temporary structures	≤ 10 years - Temporary structures
63% - Damage	1.0 - Ordinary structures	≥ 50 years - Ordinary structures
10% - Life safety	1.5 - Important structures	≤ 100 years - Important structures
5% - Collapse	2.0 - Strategic structures	

consequent the achievement of a defined limited state and then on the "importance" of the structure (Table 1).

The spectral shape for the two horizontal orthogonal components of the seismic action is given by Eq. (1); a_g is the design ground acceleration on type A site class (note that the anchoring value of the spectrum finally coincides with the PGA on rock from PSHA); S is the product of the stratigraphic factor, S_S, and the topographic amplification factor, S_T; T_B and T_C are the limiting periods of the spectrum's constant acceleration range; T_D is the lowest period of the constant displacement spectral portion; F_o is an amplification factor (equal to the ratio between the maximum spectrum ordinate and the a_g value); η is the damping correction factor (η = 1 for 5% viscous damping):

$$\begin{cases} 0 \le T < T_B : S_a(T) = a_g \cdot S \cdot \eta \cdot F_o \left[\dfrac{T}{T_B} + \dfrac{1}{\eta \cdot F_o} \left(1 - \dfrac{T}{T_B} \right) \right] \\ T_B \le T < T_C : S_a(T) = a_g \cdot S \cdot \eta \cdot F_o \\ T_C \le T < T_D : S_a(T) = a_g \cdot S \cdot \eta \cdot F_o \left(\dfrac{T_C}{T} \right) \\ T_D \le T < 4s \ : S_a(T) = a_g \cdot S \cdot \eta \cdot F_o \left(\dfrac{T_C \cdot T_D}{T^2} \right). \end{cases} \quad (1)$$

The ordinates and shapes (i.e., T_B, T_C, T_D and S) depend both on the seismic hazard level and the site class. The same stratigraphic profiles of Eurocode 8 (CEN, 2003) are considered to compute soil amplification. The vertical spectral shape is similar to the horizontal one but not reported here for the sake of brevity.

The Annex B of NIBC provides a_g, F_o and T_C^* (i.e., the T_C value for type A site class) values for 9 probabilities of exceedance in 50 years (or equivalently for 9 return periods[2]) of seismic action and for each node of a regular grid having about a 5 km spacing and covering the whole national territory. These values are derived from the above-mentioned INGV seismic hazard

[2] $T_R = -V_R / \ln(1 - P_{V_R})$. For a generic return period T_R (that doesn't fall into the set of return periods for which the spectra parameters are available in Annex B of the code), the value of the generic parameter necessary to define the spectrum may be computed by a relationship provided in Annex A.

study; in particular, F_o and T_C^* values are obtained minimizing, for a given site and for a given return period, the deviation between the code spectra and the corresponding INGV UHSs.

As an example, let's consider two neighboring sites, Nusco and Sant'Angelo dei Lombardi in the Campania region (southern Italy), whose accelerations on rock with a 10% probability of exceedance in 50 years are 0.2416 g and 0.2673 g, respectively. According to the old national seismic classification they would be classified in Zone I and II, respectively. Fig. 1a shows the location of the two sites on the Campania region hazard map in terms of PGA, with a return period of 475 years. Although the two sites are very close and then, obviously, have spectra calculated according to the NIBC very similar (Fig. 1b) the spectra determined by the OPCM 3274 (2003) were very different, and in particular that of Sant'Angelo dei Lombardi was significantly oversized with respect to the real hazard at the site. Fig. 1b also shows how the spectra of the NIBC approximate well the uniform hazard spectra for the two sites. Finally, note how the maximum value of the PGA on rock in the region, corresponding to a probability of 10% in 50 years, is about 0.27 g. This value is significantly lower than the anchor value of the spectrum, 0.35 g, provided by the former classification for a large part of the Campania region.

3. Record selection for seismic structural dynamic analysis

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 [0.15 s, 2 s] and [0.15 s, 2 T_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 [0.15 s, 2 s] and [0.15 s, 1.5 T_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, [0.15 s, 1.2 T_{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 seismogenic 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.

In the author's opinion, these prescriptions may approximate the current best practice in record selection and manipulation, that is, the seismograms 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 seismogenic features of the source of engineering interest are not always available [see, Convertito *et al*. (2009) for a discussion]. Furthermore, some studies have

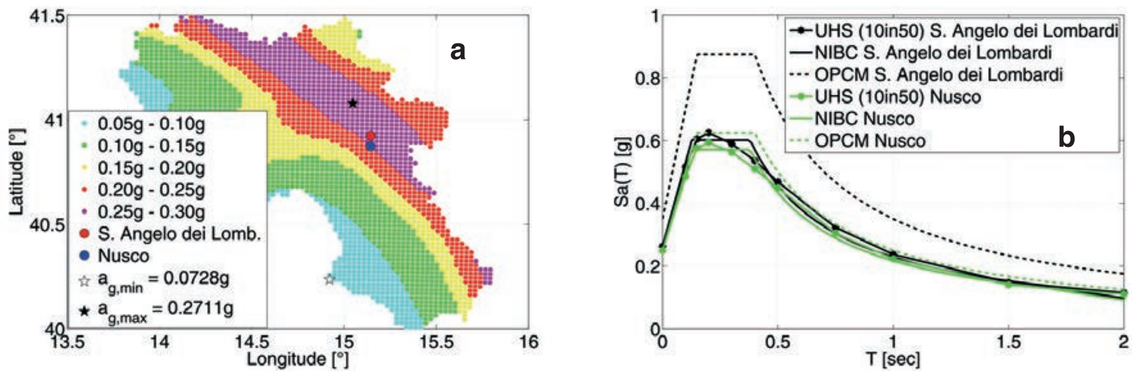

Fig. 1 - PGA on rock with a 475 years return period (a) in Campania (southern Italy) and various spectra for two close sites in the region (b).

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.

4. Computer-aided record selection for seismic analysis of structures

In the previous section, we discussed how the NIBC, can appropriately allow some degree of freedom in selecting and manipulating real records even though one has to take into account some information about the design earthquakes which is not always available to practitioners or even not strictly necessary. At the same time, although an accurate selection of seismic input on the basis of seismogenetic characteristics relevant to the site under consideration is certainly the most prudent and rational procedure, maintaining a certain degree of coherence of signals with the reference spectrum can help in cases where it is not easily feasible.

To enable the selection of records for both approaches, a specific software tool (Fig. 2) was developed. It 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).

REXEL 2.31 beta, available on the website of the Rete dei Laboratori Universitari di Ingegneria Sismica - ReLUIS (http://www.reluis.it/), contains the accelerograms from the European Strong-motion Database or ESD (http://www.isesd.cv.ic.ac.uk/), satisfying the free-field conditions and produced by earthquakes of magnitude larger than 4 (Ambraseys *et al*., 2000, 2004).

First of all, the software allows one to automatically define the reference spectra according to

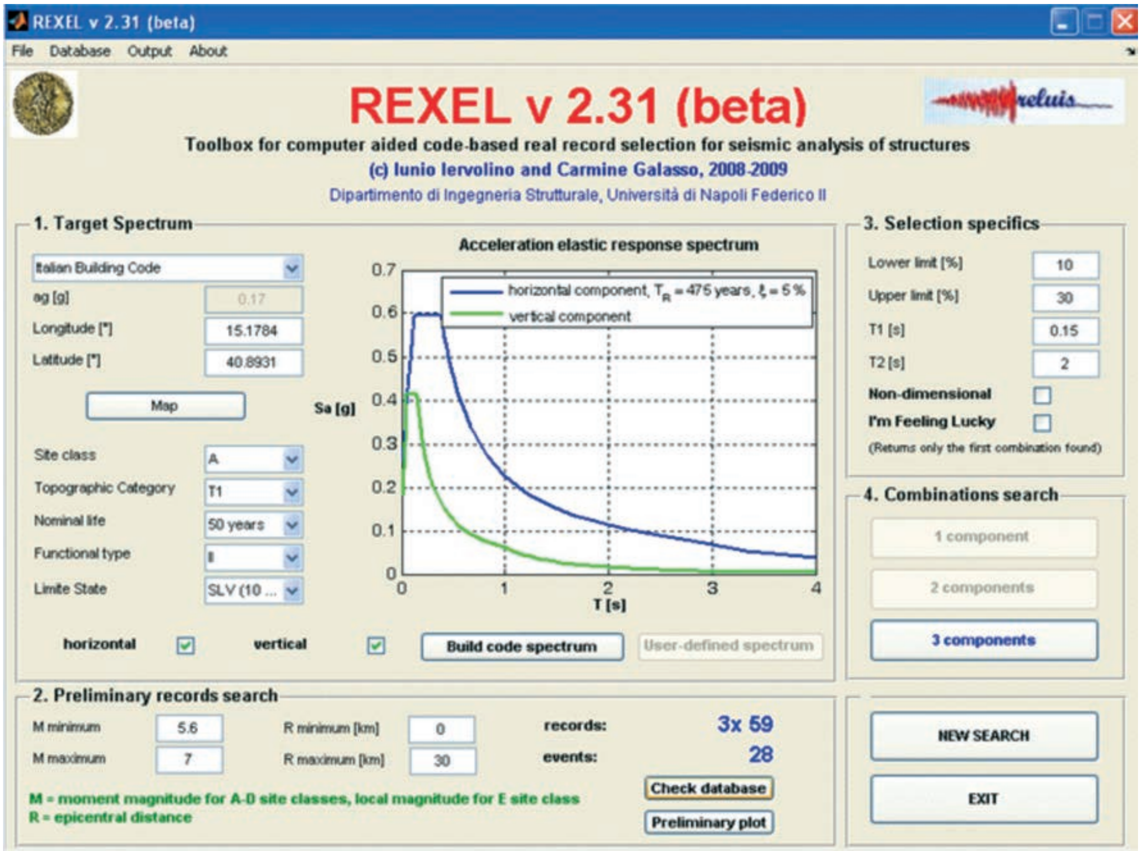

Fig. 2 - Image of the user interface of the software.

the NIBC. To do this, it is necessary to enter the geographical coordinates of the site, longitude and latitude in decimal degrees, and to specify the Site Class, the Topographic Category, the Nominal Life, the Functional Type, and the Limit State of interest. If the specified coordinates do not fall into a node of the NIBC grid, the values of the parameters needed for the definition of the target spectrum are automatically calculated as weighted averages of the values that the parameters assume in the vertices of the elementary mesh that contains the site, using as weights, the reciprocal of the distances between the site and the four nodes, as specified in Annex A of NIBC. Moreover, the software allows one to search the records of the ESD database (embedded in REXEL) belonging to the same local geology category of the site in question and eventually corresponding to a given pair of magnitude and epicentral distance of interest. For this, the user must specify the intervals [M_{min}, M_{max}] (moment magnitude) and [R_{min}, R_{max}] (epicentral distance, in kilometers) where the accelerograms have to fall. Then, the software returns the number of records (and the corresponding number of events) available in these ranges.

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 compatible ones, in an average sense, with the defined reference spectrum for the site of interest. To do this, the user also has to specify

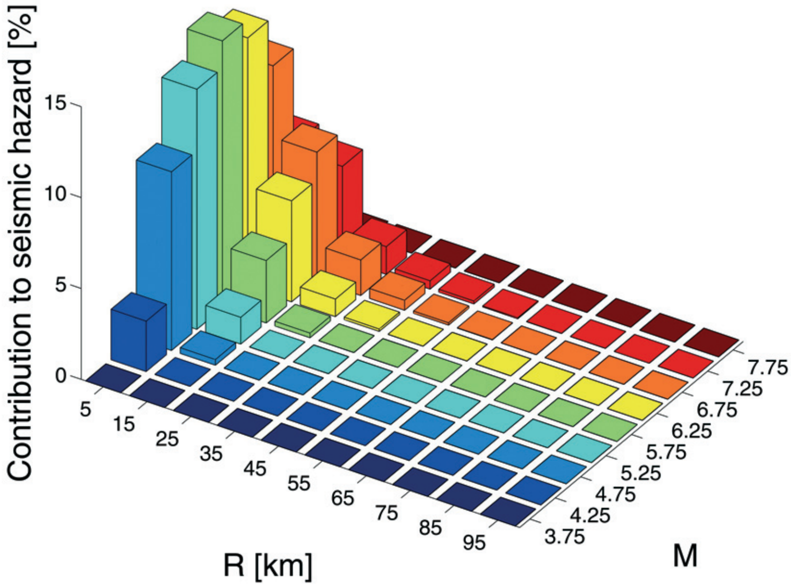

Fig. 3 - Disaggregation of seismic hazard in terms of PGA for Sant'Angelo dei Lombardi for T_R = 475 years (from INGV data).

the tolerance needed for the average spectrum of the combination to match the target spectrum in an arbitrary interval of periods [T_1, T_2] between 0 s and 4 s.

The compatible combination can comprise 7 accelerograms to be applied in one direction (horizontal and/or vertical) 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; 7 groups of accelerograms which include the two horizontal plus the vertical recordings of 7 recording stations.

REXEL 2.31 beta 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 combinations whose spectra are generally more similar to the target spectrum, so reducing the record-to-record spectral variability within a set.

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 results of the analysis are sorted so that record combinations which have the smallest deviation from the target spectrum [according to the deviation parameters defined in Iervolino *et al*. (2008)] are at the beginning of the output list.

The user can also select the option *I'm feeling lucky* in order to stop the analysis after the first compatible combination is found. This option, in most cases, allows one to get a combination compatible with the reference spectrum immediately, otherwise, the search may take a long time.

The illustrative examples below show how to use the tool developed and how the NIBC

Table 2 – Information about compatible sets found for Sant'Angelo dei Lombardi.

Combination	M_{mean}	R_{mean}	SF_{mean}
1 component un-scaled	6.7	20.7	-
2 components un-scaled	6.6	18.3	-
1 component scaled	6.6	16.9	1.9
2 components scaled	6.6	15.1	1.9

generally facilitates the selection of accelerograms for nonlinear dynamic analysis of structures.

5. Example 1. Selection for Sant'Angelo dei Lombardi

To take an example let's consider the selection of horizontal accelerograms according to the NIBC for the life safety limit of an ordinary structure (Functional Class II) located in Sant'Angelo dei Lombardi (longitude: 15.1784°E, latitude: 40.8931°N) on soil type A with a nominal life of 50 years, which corresponds to the design for a 475 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.

Let's also consider that the selection should reflect the disaggregation of the PGA hazard on rock with a 10% probability of exceedance in 50 years (Fig. 3) at the site. Specifying the M and R intervals at [5.6, 7] and [0 km, 30 km] respectively, REXEL 2.31 beta found 177 records (59 x 3 components of motion) from 28 different earthquakes. Records in M and R intervals were selected because there were no compatible combinations corresponding exactly to the modal M-R pair provided by disaggregation; moreover, there are also other values of magnitude and distance, close to the modal values, contributing significantly to the seismic hazard.

When assigning, as tolerance for the average spectral matching, 10% lower and 20% upper in

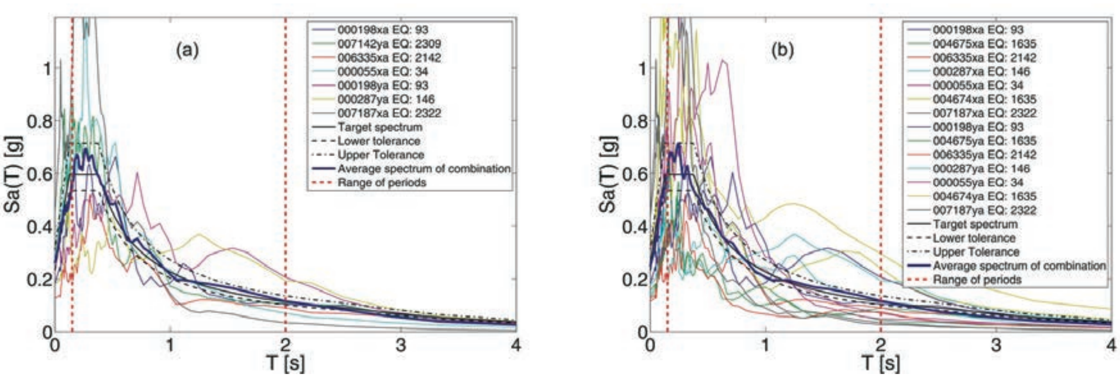

Fig. 4 - Combinations found for the assigned example in Sant'Angelo dei Lombardi using the *I'm feeling lucky* option in the case of horizontal 1- (a) and 2-components (b) ground motions.

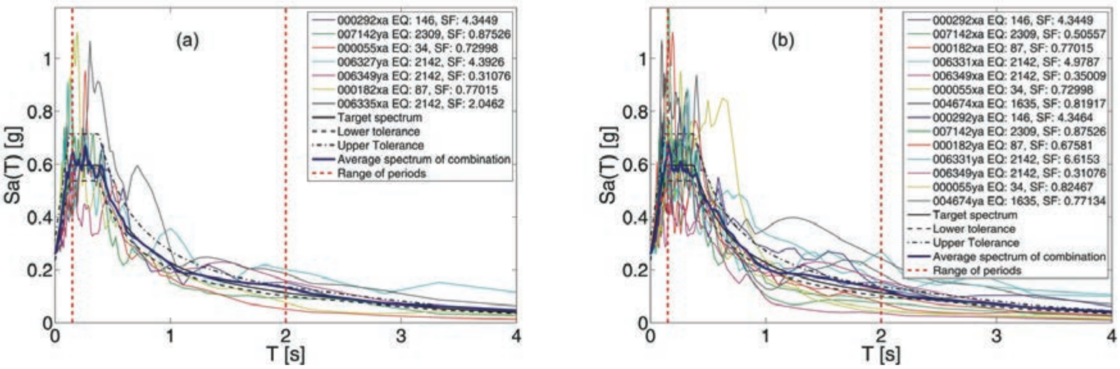

Fig. 5 - Scaled combinations found for the assigned example in Sant'Angelo dei Lombardi using the *I'm feeling lucky* option in the case of horizontal 1- (a) and 2-components (b) ground motions.

the period range 0.15 s ÷ 2 s and selecting the option to stop the search after the first combination is found (i.e., *I'm feeling lucky*), REXEL immediately returns the combinations of accelerograms in Fig. 4a 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 ESD station and component codes, along with the earthquake code, are also given. Table 2 reports the mean values of magnitude and distance of the two combinations. Detailed information on the spectra of the sets, which are automatically provided by the software, can be also derived from the ESD website.

When selecting the option to search for a set of seven pairs of horizontal components (e.g., for the analysis of 3D structures), instead, the software returns the 14 records of Fig. 4b. Note that in this case the records are 7 pairs of both horizontal components of only 7 recordings.

The results presented show that the deviation of the individual spectra compared with the target can be large (e.g., Fig. 4b). To reduce the scatter of individual records further, the non-dimensional option[3] can be used, which means that records found have to be linearly scaled when used in a structural analysis for spectral matching on the average. In this case, repeating the search for Sant'Angelo dei Lombardi simply considering accelerograms with $M \geq 6$ and distance 0 km ÷ 25 km, with the same compatibility criteria as the previous case and using the *I'm feeling lucky* option, the software immediately returns the combinations shown in Figs. 5a and 5b, which feature records with less scattering with respect to the un-scaled ones of Fig. 4. The records in Fig. 5 are multiplied by the scaling factors (SFs, automatically computed and shown in the legend) required to render the set compatible with the code spectrum in the case of a non-dimensional search.

In Table 2, the mean values of magnitude, distance and the SF of the two combinations are

[3] 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 preliminary 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 scaled to be compatible in an average sense with the reference spectrum.

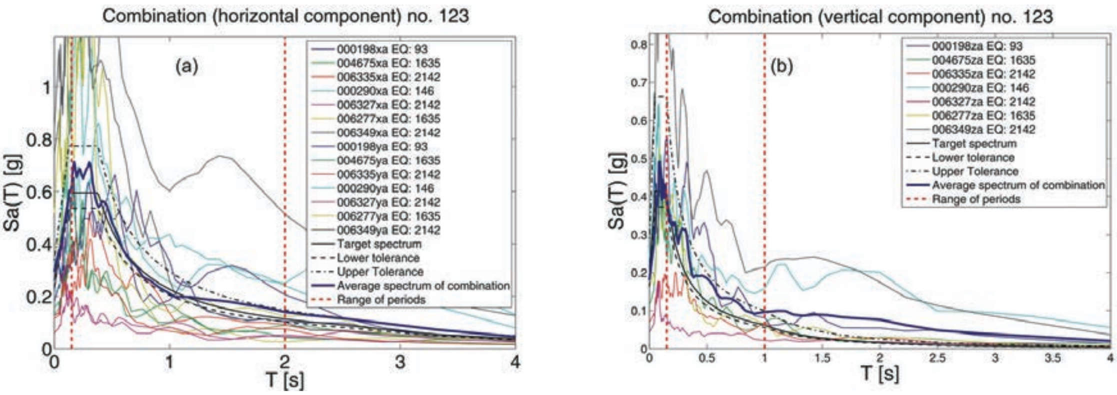

Fig. 6 - First combination found for the assigned example in Sant'Angelo dei Lombardi which includes the two horizontal (a) and the third vertical (b) ground motion components.

given. Note also that REXEL asks for the maximum value that the average scale factor (SF_{mean}) can assume, which in this case was limited to 2.

5.1. Search that includes the vertical component of seismic motion

REXEL 2.31 beta allows one to select combinations of accelerograms that include the vertical component of motion, although the NIBC requires it to be accounted for only in particular cases. Considering the example in Sant'Angelo Lombardi once again, and specifying as magnitude and distance intervals [6, 7] and [0 km, 50 km] respectively, REXEL found 52 groups of accelerograms from 19 events.

When assigning a tolerance compatibility as an average of 10% lower and 30% upper for the horizontal component, and 10% lower and 60% upper for the vertical component, in the range of periods 0.15 s ÷ 2 s (for the horizontal components) and 0.15 s ÷ 1 s (for the vertical component), the software returns 22717 combinations compatible with the horizontal target spectrum, 631 of which are also compatible with the vertical reference spectrum.

Finally, note that when searching for combinations that include the vertical component, it may not be appropriate to use the *I'm feeling lucky* option. In fact, the first combination compatible with the horizontal code spectrum (returned by the software) may not necessarily satisfy the compatibility criteria with the vertical spectrum. For example, in the considered case the first combination where all the three components match the target spectra (Fig. 6) only comes after 122 combinations which are found to match the horizontal spectrum.

6. Example 2. Selection for the Ospedale del Mare

The Ospedale del Mare is a hospital currently under construction in Naples, and it is the largest isolated seismic structure in Europe. Its plan is about 150 x 150 m^2, the maximum height of the building is about 30 m; the structure has a seismic weight of about 100,000 tons. The seismic protection system used consists of 327, isolating rubber bearings determining an

Fig. 7 - The construction site of the Ospedale del Mare.

equivalent period of the structure of about 2 s (Di Sarno *et al.*, 2006). Fig. 7 shows the construction site, which is on soil type B according to Eurocode 8 (CEN, 2003).

Let's consider the selection of horizontal records according to the NIBC for the operability limit state for the hospital (Functional Class IV) with a nominal life of 100 years which corresponds to the design for a 120-years return period according to the code.

Fig. 8 shows the disaggregation of the PGA hazard (in terms of M and R), as derived from http://esse1-gis.mi.ingv.it, for a return period of 140 years, which is the closest available to 120 years. The first modal pair is close to magnitude 5 at 5 km, while a second peak, which gives a relatively smaller contribution to the hazard is related to earthquakes of magnitude around 7 as well as being more distant.

Setting the coordinates of the site (longitude: 14.3446°E, latitude: 40.8316°N) and the other parameters to define the seismic action according to the NIBC, REXEL automatically builds the elastic design spectrum.

Specifying the magnitude and distance interval equal to [5, 7] and [0 km, 30 km] respectively (i.e., intervals chosen on the basis of the first modal pair from disaggregation), REXEL finds 151 pairs of accelerograms in the database from 79 different earthquakes (both horizontal components of motion). Assigning a compatibility tolerance with respect to the average spectrum of 10% lower and 20% upper in the period range 0.15 s ÷ 2.47 s and selecting the quick search option, the software immediately returns the combinations of accelerograms in Fig. 9a.

Selecting the non-dimensional option, the software immediately returns the combinations of Fig. 9b. The mean SF was limited to 2; information on mean values of magnitude and distance and SFs are given in Table 3.

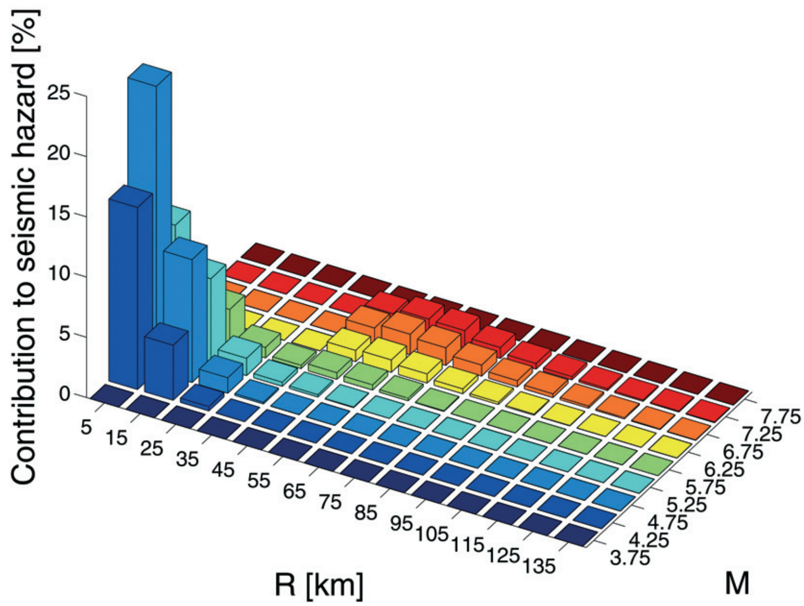

Fig. 8 - Disaggregation of seismic hazard (in terms of PGA on rock) for a 140 years return period for the construction site.

Specifying the magnitude and distance intervals equal to [6.2, 7.4] and [50 km, 90 km] respectively (i.e., intervals chosen on the basis of the second modal pair from disaggregation), REXEL 2.3 beta finds 26 pairs of accelerograms in the database from 18 different earthquakes. Assigning a compatibility tolerance with respect to the average spectrum of 10% lower and 30% upper in the period range 0.15 s ÷ 2.47 s and selecting both the dimensionless and the *I'm feeling lucky* options, the software immediately returns the combination shown in Fig. 10a. The mean scale factor was limited to 4.

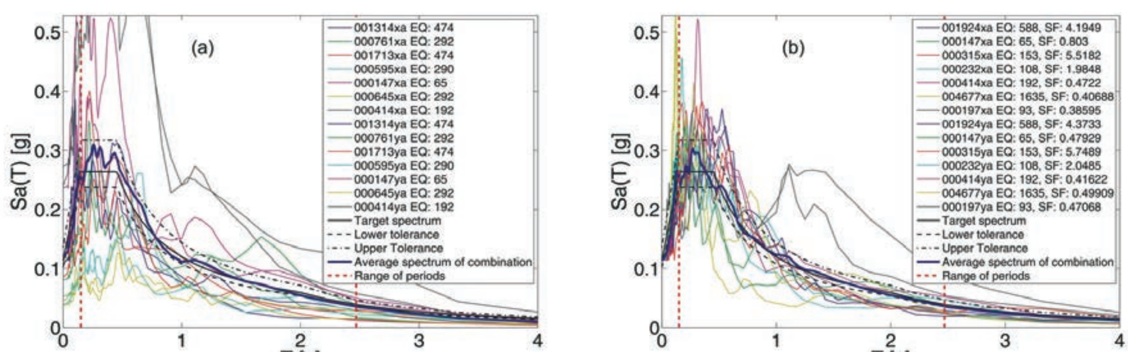

Fig. 9 - Combinations found for the Ospedale del Mare, scaled (a) and un-scaled (b), related to the first modal pair from disaggregation.

Table 3 – Information on compatible sets shown for the Ospedale del Mare.

Combination	M_{mean}	R_{mean}	SF_{mean}
Based on the first modal pair from disaggregation (un-scaled)	5.8	18.9	-
Based on the first modal pair from disaggregation (scaled)	6.0	18.4	1.9
Based on the second modal pair from disaggregation (un-scaled)	6.9	45.9	-
Based on the second modal pair from disaggregation (scaled)	6.6	72.4	3.7

To find an un-scaled compatible combination it was chosen to increase only the distance range (i.e., specifying a distance interval equal to [0 km, 100 km]) thus enlarging the number of records for the search for compatible sets (from 26 pairs corresponding to 18 events to 69 pairs from 21 different events). Thanks to the *I'm feeling lucky* option, the program returns the combination of Fig. 10b in seconds. Information about mean values of magnitude and distance and SFs are given in Table 3.

7. Conclusions

This paper presented a software tool developed for the automatic selection of combinations of seven recordings compatible, in an average sense, with a target spectrum defined according to the new Italian building code (and others) for seismic structural analysis. REXEL 2.31 beta, available at the website of the Italian consortium of earthquake engineering laboratories: Rete dei Laboratori Universitari di Ingegneria Sismica – ReLUIS (http://www.reluis.it/), allows multiple selection options, that reflect not only the criterion of compatibility with the target spectrum, but also consider of dominant seismic events (in terms of magnitude and epicentral distance) for any of the three components of motion.

The program analyzes all combinations of seven groups of spectra defined by the input

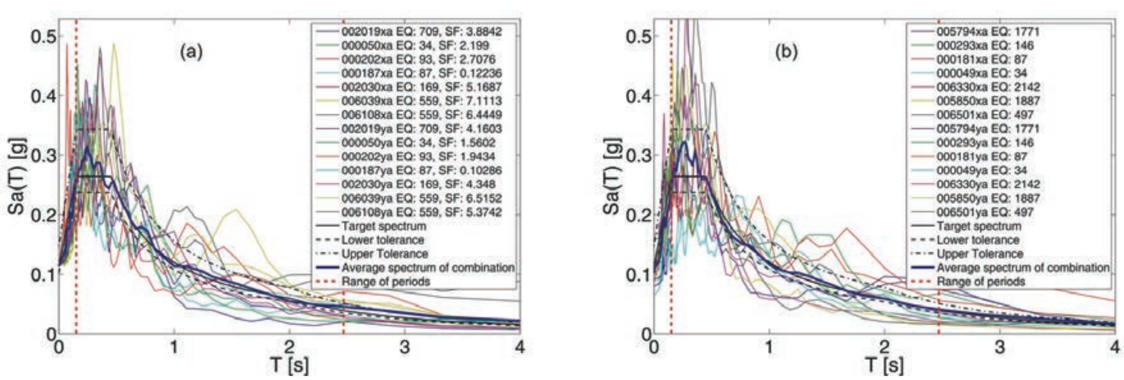

Fig. 10 - Combinations found for the Ospedale del Mare, scaled (a) and un-scaled (b), related to the second modal pair from disaggregation.

parameters and returns a list of those sets whose average spectrum is compatible with the target within the chosen period range and with the tolerances accepted. The records used to find spectrum-compatible sets, are automatically sorted on the basis of their deviation with respect to the code (reference) spectrum.

As the illustrative examples demonstrate, the selection of spectrum-compatible records can be facilitated significantly by REXEL.

Acknowledgements. The study presented in this paper was developed within the activities of the Rete dei Laboratori Universitari di Ingegneria Sismica - ReLUIS for the research program funded by the Dipartimento di Protezione Civile 2005-2008.

REFERENCES

Ambraseys N., Smit P., Berardi R., Rinaldis D., Cotton F. and Berge C.; 2000: *Dissemination of European strong-motion data (Cd-Rom Collection)*. European Commission, DGXII, Science, Research and Development, Bruxelles.

Ambraseys N., Smit P., Douglas J., Margaris B., Sigbjornsson R., Olafsson S., Suhadolc P. and Costa G.; 2004: *Internet-site for European strong-motion data*. Boll. Geof. Teor. App., **45**, 113-129.

Bazzurro P. and Cornell C.A.; 1999: *Disaggregation of seismic hazard.* Bull. Seism. Soc. Am., **89**, 501-520.

CEN, (European Committee For Standardisation); 2003: *Eurocode 8: Design provisions for earthquake resistance of structures, Part 1.1: general rules, seismic actions and rules for buildings*. Structures. PrEN1998-1, Bruxelles.

Convertito V., Iervolino I. and Herrero A.; 2009: *The importance of mapping the design earthquake: insights for southern Italy*. Bull. Seis. Soc. Am., **99**, 2979-2991, doi: 10.1785/0120080272.

CS.LL.PP.; 2008: *Decreto Ministeriale 14 gennaio 2008: Norme tecniche per le costruzioni*. In: Gazzetta Ufficiale della Repubblica Italiana, n. 29, 4 febbraio 2008, Suppl. Ordinario n. 30. Ist. Polig. e Zecca dello Stato S.p.a., Roma, (in Italian).

CS.LL.PP.; 2009: *Istruzioni per l'applicazione delle norme tecniche delle costruzioni*. In: Gazzetta Ufficiale della Repubblica Italiana, n. 47, 26 febbraio 2009, Suppl. Ordinario n. 27, Ist. Polig. e Zecca dello Stato S.p.a., Roma, (in Italian).

Iervolino I. and Cornell C.A.; 2005: *Record selection for nonlinear seismic analysis of structures*. Earthq. Spectra, **21**, 685-713.

Iervolino I., Maddaloni G. and Cosenza E.; 2008: *Eurocode 8 compliant real record sets for seismic analysis of structures*. J. Earthq. Eng., **12**, 54–90.

Iervolino I., Galasso C. and Cosenza E.; 2009: *REXEL: computer aided record selection for code-based seismic structural analysis*. Bull. Earthq. Eng. doi: 10.1007/s10518-009-9146-1 (in press).

Montaldo V., Meletti C., Martinelli F., Stucchi M. and Locati M.; 2007: *On-line seismic hazard data for the new Italian building code*. J. Earthq. Eng., **11**, 119–132.

OPCM 3274; 2003: *Ordinanza 20 marzo 2003, n. 3274: Primi elementi in materia di criteri generali per la classificazione sismica del territorio nazionale e di normative tecniche per le costruzioni in zona sismica*. In:

Gazzetta Ufficiale della Repubblica Italiana, n. 105, 8 maggio 2003, Suppl. Ordinario n. 72, Ist. Polig. e Zecca dello Stato S.p.a., Roma, (in Italian).

OPCM 3431; 2005: *Ordinanza 3 maggio 2005, n. 3431: Ulteriori modifiche ed integrazioni all'Ordinanza del presidente del Consiglio dei Ministri N. 3274*. In: Gazzetta Ufficiale della Repubblica Italiana, n. 107, 10 maggio 2005, Suppl. Ordinario n. 85, Ist. Polig. e Zecca dello Stato S.p.a., Roma, (in Italian).

OPCM 3519; 2006: *Ordinanza 28 aprile 2006, n. 3519: Criteri per l'individuazione delle zone sismiche e la formazione e l'aggiornamento degli elenchi delle medesime zone*. In: Gazzetta Ufficiale della Repubblica Italiana, n. 108, 11 maggio 2006, Ist. Polig. e Zecca dello Stato S.p.a., Roma, (in Italian).

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