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Use of the Artificial Neural Networks to Estimate the DRF for Eurocode 8

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RESEARCH ARTICLE

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Abstract
The damping reduction factor (DRF) is used in earthquake engineering in order to estimate the seismic response of buildings with high damping ratio from the one which has damping ratio equal to 5%. Many expressions were given to this factor as a function of different parameters in literature. The concern of these formulations is to find a simple and a reliable formulation, which presents a challenge. This is the major reason to look for a new simple method to estimate the DRF values with a good approximation. The primary objective of this work is to develop a new method to estimate the DRF using Artificial Neural Networks (ANN). This method is developed for the seismic Eurocode 8 (EC8). In a first step, seeking for sets of ground motions records that gives as average the best approximation of the target spectra of EC 8. Afterward, those records are used to estimates the exact response spectra and the DRF values in function of damping ratio ξ and period (T) through a time History Analysis. In a second step, those results are used as neural networks database to predict the DRF in function of ξ and T. The proposed approach is original and the associated results are interesting and promising.

Keywords
ground motions, Damping Reduction Factor (DRF), Artificial Neural Networks (ANN), Eurocode 8

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1 Introduction

In the most seismic codes throughout the world, the response spectrum is given for a damping ratio $\xi = 5\%$. Civil structures, however, may have different values of damping. As a result, the 5% response spectrum should be adjusted to other damping levels through a correction factor to evaluate the spectral response for any damping l.

Different symbols are cited in the literature to identify this correction factor. For instance, DCF "Damping Correction Factor" is used in [1–4], "Damping reduction factor" is used by [5–9], and several other researchers. "Damping modification factor" is used in [10–13]. Other terminologies that have seen in the literature include: damping adjustment factor, response spectrum amplification factor, and the damping scaling factor. In this study, we adopt the term Damping Reduction Factor (DRF).

This factor has been studied by a number of researchers. Moreover, many expressions were given to this factor as a function of many parameters, damping only [3, 4, 14–16], Damping and period [6, 17–21], or other parameters Duration, Soil conditions, Distance, Magnitude).

One of the first systematic methods, for adjusting 5%-damped spectra to other levels of damping, was the pioneer work of Newmark and Hall [22] where their results inspired many seismic codes and Norms. It was based on only 28 records from 9 earthquakes prior to 1973. This work is the basis for most U.S. building codes. They divided their results of damping reduction factors into three parts: the acceleration-, velocity-, and displacement-sensitive regions, respectively. The model of Newmark and Hall is only applicable for $\xi < 20\%$ and for T in the range 0.125–10 sec. In Lin and Chang [6], a total of 1053 earthquake acceleration time histories from 102 earthquakes recorded in the United States of America. They concluded that the damping reduction factors are functions of the structural period and the damping ratio. Its applicability is ξ -2-50 % and T 0.01–10 sec.

Hatzigeorgiou [12] in his paper proposed a new method to estimate DRF of SDOF systems on the basis of empirical expressions obtained after extensive parametric studies. The influence of viscous damping ratio, period of vibration, soil type conditions and ground motion type (natural near- and far-fault and artificial accelerograms) are carefully examined and discussed. A complete nonlinear regression analysis is carried out on the basis of the data obtained by the aforementioned response analysis. The relation of DRF versus the structural period and viscous damping ratio is regressed in such a way so that the effect of soil type and the type of seismic ground motion should be also taken into account.

Stafford et al [2] in their paper confirmed the dependence of damping reduction factors for response spectra on duration and numbers of cycles inferred by Bommer and Mendis [23] They quantified this dependence through the development of equation for predicting spectral scaling factors as functions of these parameters. Its applicability is in the interval of ξ 2–55%. Cameron and Green [1] proposed an equation for the damping reduction factors for $\xi \geq 2\%$ vary as a function of general site classification, earthquake magnitude, and tectonic setting. Its Applicability is limited in $T = 0.05$–10 sec $\xi = 1$–50%, Magnitude bins: 5–6, 6–7, 7+, Distance bins: 0–50, 50–200 km.

Lin et al [5] have made a comparison and an evaluation of existing models against a database of recorded motions. They evaluated the accuracy of five types of damping reduction factors for estimating the maximum elastic displacement demands of SDOF systems by using 216 ground motions recorded on firm sites in California. In the work of Lin et al [7] , a comprehensive statistical study of the damping reduction factors considering the effects of site conditions has been carried out by using 1037 earthquake acceleration time histories recorded on three different site categories (site Class AB = rock, site Class C = very dense soil, and site Class D= stiff soil). Expressions obtained from nonlinear regression analysis by using the Levenberg– Marquardt method which are proposed in the end of their paper in order to estimate the damping reduction factors derived from the displacement and acceleration responses. The resulting equations for the damping reduction factors derived from the displacement response spectrum corresponding to each site class.

Almost of the cited papers used the linear or nonlinear regression to establish a formulation of the damping reduction factor. The disadvantages of those expressions are the exactitude which is not always so good and the complications of those expressions in function of many parameters. This is the main reason to find out a new method to DRF estimation with a good approximation. The objective of this study is to evaluate the accuracy of the neural networks to predict the DRF according to the Eurocode 8 response spectra.

2 Ground Motion selection using REXEL

Rexel is a tool that allows the user to select sets of strong ground motion records that are representative of design ground motions. The user specifies the target response spectrum and the desired characteristics of the earthquake ground motions in terms of earthquake magnitude, source-to-site distance and other seismic characteristics. Rexel then selects the records from the internal database of ground motion records that satisfy the user-specified selection criteria and provide good fits to the target response spectrum.

Like many worldwide codes, Eurocode 8 (EC8) allows the use of real ground-motion records for the seismic analysis of structures. The main condition to be satisfied by the selected set is that the average elastic spectrum does not underestimate the code spectrum, with a 10% tolerance, in a broad range of periods depending on the structure's dynamic properties. The EC8 prescriptions seem to favor the use of spectrum matching records, obtained either by simulation or manipulation of real records [24].

The average spectrum deviation (δ) gives a quantitative measure of how much the spectrum of a record deviates from the spectrum of the code. The definition of (δ) is giving by Eq(1).

$$\delta = \left\{ \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left(\frac{Sa_0(T_i) - Sa_s(T_i)}{Sa_s(T_i)} \right)^2} \right\} \quad (1)$$

Where $Sa_0(T_i)$ represents the pseudo-acceleration ordinate of the single reTicord corresponding to the period T_i while $Sa_s(T_i)$ is the value of the spectral ordinate of the code spectrum at the same period, and N is the number of values within the considered range of periods. Selecting a record set with low (δ) value allows obtaining of an average spectrum, which is tended to be as close as possible to the code spectrum.

Controlling this parameter may allow choosing combinations characterized by records having the individual spectra relatively close to the reference spectrum, and therefore being narrowly distributed around it.

In fact, it was hard to find record sets which are close to the response spectra. In this work, A set of records which are as close as possible to the Eurocode spectra with different site class with design ground acceleration $a_g = 0.35$. For each site class we selected 25 records according to its average spectrum deviation (δ).

In Figures 1, 2, 3, the spectrums of the selected records are represented with its mean spectrums and target spectrums. In the most of the compatibility interval, they approximate very well the design spectral shape.

For the types of soils D and E, no results at all were found. This is primarily due to the number limitation of records on these soils in the data-base.

A full list for all records found for each soil class with their characteristics was presented in the Tables 1, 2, 3.

3 Artificial Neural Network Analysis

3.1 Network design

In order to obtain more realistic prediction of the damping reduction factor, a contemporary data analysis technique, which is capable of searching nonlinear relationships more thoroughly, has been employed. This technique is the neural network analysis.

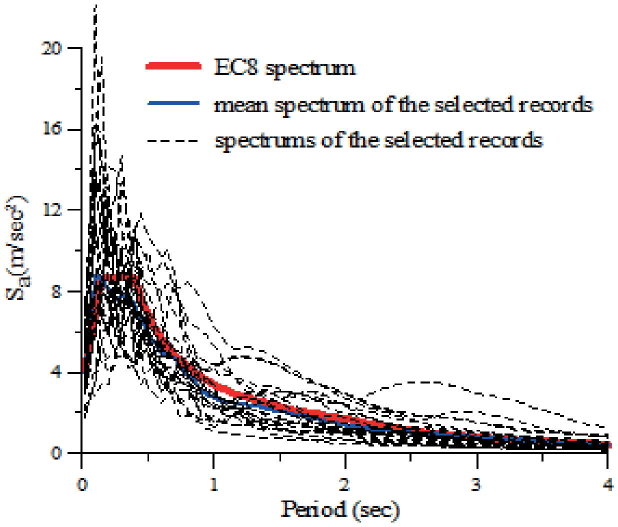

Fig. 1 Response spectrums of the records returned by REXEL for the soil A

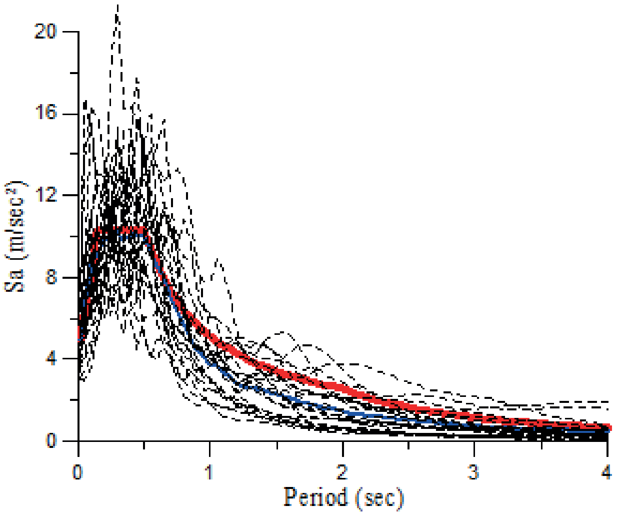

Fig. 2 Response spectrums of the records returned by REXEL for the soil B

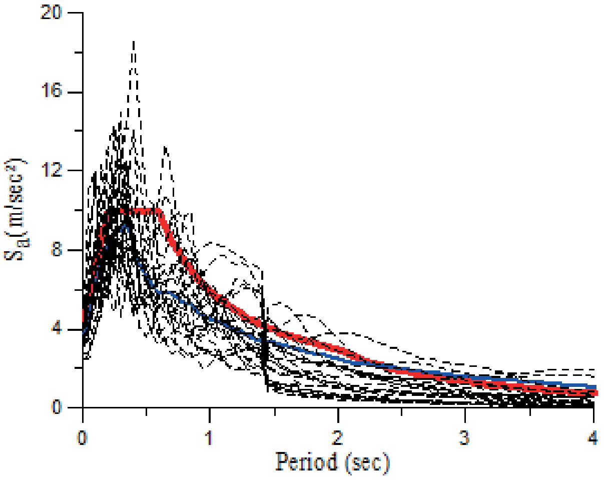

Fig. 3 Response spectrums of the records returned by REXEL for the soil C

Neural network constitutes a branch of artificial intelligence which has recently undergone rapid evolution and progress. Its development started in the 1940s to help cognitive scientists understand the complexity of the nervous system [25]. An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the learning process in the human brain, the key element of this paradigm is the structure of the information processing system. This computational technique has the ability to learn in a similar way to people. It is capable of recognizing, capturing and mapping features known as patterns contained in a set of data mainly due to the high interconnections of neurons that process information in parallel. A network that has learned the patterns defining the relationship between the input and output of a certain test or process can later be used to predict new conditions for which the results (output) are not known. In this study, we have used the feed-forward multi-layer neural network.

Table 1 records data returned by REXEL for the soil A

Earthquake ID	component	Station ID	Earthquake Name	Date	Mw	Vs30 (m/s)	Epicentral Distance (km)
34	X, Y	ST20	Friuli	06/05/1976	6,5	1021	23
87	X, Y	ST54	Tabas	16/09/1978	7,3	826	12
93	X, Y	ST64	Montenegro	15/04/1979	6,9	1083	21
146	X, Y	ST96	Campano Lucano	23/11/1980	6,9	1100	32
1635	X	ST2486	South Iceland	17/06/2000	6,5	-	5
1635	X, Y	ST2558	South Iceland	17/06/2000	6,5	-	15
2142	X	ST2483	South Iceland (aftershock)	21/06/2000	6,4	-	6
2142	X	ST2558	South Iceland (aftershock)	21/06/2000	6,4	-	5
497	X	ST3136	Duzce 1	12/11/1999	7,2	-	23
2309	Y	ST539	Bingol	01/05/2003	6,3	806	14
41	X, Y	ST_106	South Iceland	2000_June_17	6,5		5,25
101	X, Y	ST_113	Olfus	2008_May_29	6,3		8,89
101	X, Y	ST_112	Olfus	2008_May_29	6,3		8,25
101	Y	ST_101	Olfus	2008_May_29	6,3		7,97
147	X, Y	MQZ	Christchurch	2011_June_05	5,1		25,3
94	Y	ST_47379	Loma Prieta	1989_Oct_18	6,9	1428	28,57

Table 2 records data returned by REXEL for the soil B

Earthquake ID	component	Station ID	Earthquake Name	Date	Mw	Vs30 (m/s)	Epicentral Distance (km)
93	x, y	ST62	Montenegro		6,9	464	25
250	y	ST205	Erzincan		6,6	421	13
1635	y	ST2482	South Iceland	17/06/2000	6,5	-	15
1635	y	ST2554	South Iceland	17/06/2000	6,5	-	144
2142	y	ST2484	South Iceland (aftershock)		6,4	-	12
27	y	KGS005	NW Kagoshima Prefecture	19/05/1997	6	390	15,7
41	y	ST_105	South Iceland	2000_June_17	6,5		14,56
50	x	ISK003	Off Noto Peninsula	2007_Marc_25	6,7	558	27,17
64	x, y	AQG	L'Aquila mainshock	2009_Apri_06	6,3	685	4,39
64	x, y	AQV	L'Aquila mainshock	2009_Apri_06	6,3	474	4,87
122	y	NIG023	MID NIIGATA PREF	2011_Marc_11	6,2	626	5,97
94	x	LGPC	Loma Prieta	1989_Octo_18	6,9	477,7	18,75
143	x	HVSC	Christchurch	2011_Febr_22	5,5	-	4,1
35	x	HEC	Hector Mine	1999_Octo_16	7,1	684,9	28,61
72	x	TLM1	Friuli 1st shock	1976_May_06	6,4	522	21,72
83	x	ST_36408	Parkfield	2004_Sept_28	6	371	3,02
83	x	ST_36411	Parkfield	2004_Sept_28	6	438	12,49
86	x, y	KAR	Gazli	1976_May_17	6,7	659,6	12,78
94	x	ST_57007	Loma Prieta	1989_Octo_18	6,9	462	7,1
94	y	ST_47006	Loma Prieta	1989_Octo_18	6,9	730	28,83
94	y	ST_58065	Loma Prieta	1989_Octo_18	6,9	371	27,59

Table 3 records data returned by REXEL for the soil C

Earthquake ID	component	Station ID	Earthquake Name	Date	Mw	Vs30 (m/s)	Epicentral Distance (km)
16	x	NIG020	Mid Niigata Prefecture	2004_October_23	6,6	354	11,09
54	y	SZO016	S Suruga Bay	2009_August_10	6,2	232	18,45
137	y	DFHS	Darfield	2010_Septemb_03	7,1	-	9,06
137	y	DSLC	Darfield	2010_Septemb_03	7,1	-	13,31
137	x, y	HORC	Darfield	2010_Septem_03	7,1	-	17,82
137	y	ROLC	Darfield	2010_Septemb_03	7,1	-	16,97
142	y	RHSC	Christchurch	2011_February_21	6,2	-	13,73
77	x, y	AI_137_DIN	Dinar	1995_October_01	6,4	198,1	0,47
89	x	AEP	Imperial Valley	1979_October_15	6,5	274,5	2,31
89	x, y	EC04	Imperial Valley	1979_October_15	6,5	208,9	27,03
89	x, y	EC05	Imperial Valley	1979_October_15	6,5	205,6	27,68
89	x, y	EC06	Imperial Valley	1979_October_15	6,5	203,2	27,35
94	x	ST_47125	Loma Prieta	1989_October_18	6,9	288,6	9,3
94	x, y	ST_47380	Loma Prieta	1989_October_18	6,9	271	29,66
99	x	ST_24087	Northridge	1994_January_17	6,7	298	11,02
99	y	ST_24303	Northridge	1994_January_17	6,7	316	23,62
78	x, y	ERZ	Erzincan	1992_March_13	6,6	274,5	8,97
39	y	AI_011_DZC	Duzce	1999_November_12	7,1	282,2	5,27

3.2 Multi-layer feed-forward (MLF) neural networks

MLF neural networks are the most used neural networks. They are applied to a wide variety of engineering related problems. A MLF neural network consists of neurons that are ordered into layers (Fig. 4). The first layer is called the input layer, the last layer is called the output layer in which the neurons are distributed in layers in such a way that two consecutive layers are fully connected; all the neurons of an input layer receive the outputs of all neurons in the previous layer. In feed-forward ANN, the neurons are organized in layers. There are no connections among neurons within the same layer; connections only exist between successive layers. Each neuron from layer l has connections to each neuron in layer $l + 1$.

A signal propagates from the input layer to the output layer through several hidden layers. For each set of input signals, Feed-forward ANNs (Fig 4) allow information to travel one way only; from input to output. There is no feedback (loops) i.e. the output of any layer does not affect that same layer. A cell performs a weighted sum in which a transfer function is applied, and the output is transmitted to the following layer.

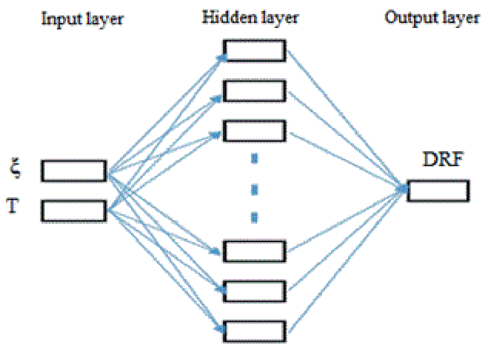

Fig. 4 Feed-forward multi-layer neural network.

The number of hidden layers, the number of cells per layer and their connections define the architecture of the neural network. The transfer function allowing to calculate the cell output is often a linear sigmoidal function [26].

The activation functions need to be differentiable and they are usually of the sigmoid shape. The most common activation function is

$$f(\theta)=\frac{1}{1+e^{-\theta}}. \tag{2}$$

That is explained the general topology of a multilayer feed forward neural network. Neurons in each layer connect together by a weight coefficient. There is a transfer function which changes inputs to an output. Before using an artificial neural network, it is necessary to train network. Neural training is a method used to calculate the synaptic weights and bias in an iterative way until produces data compatible outputs. During training, network works with iterative method until it produces a new output. At the beginning of training process, initial weights are randomly given to connections. Inputs are inserted into input layer and then move forward through the hidden layer of neurons to the output layer. At the end, outputs would be compared with real outputs [25].

The choice of the architecture network is very important, as it affects both the model precision and the computing time. In order to determine the optimal architecture, we have considered various numbers of neurons in the hidden layer. For this purpose, we have considered the number of neurons in the hidden layer to be equal to 32. The configuration of the ANN is 2-32-1; it expresses a neural network of 2 neurons in the input layer, 32 neurons in the hidden layer and 1 neuron in the output layer.

3.3 Databases

To build the database, the input parameters are the two structure characteristics in which the damping reduction factor depends, the damping ratio and the period value.

The output parameter corresponds to the damping reduction factor. These values of DRF are obtained through linear time-history analysis of SDOF with vibration period T and damping ratio ξ.

A total of 285,000 response spectra and damping reduction factors was computed from the selected ground motions corresponding to 75 ground motions, 200 periods of vibration from 0.1 to 10 s, 19 levels of damping ratio from 0.01 to 0.25, for response spectrum of the displacement were computed for each period and each damping ratio.

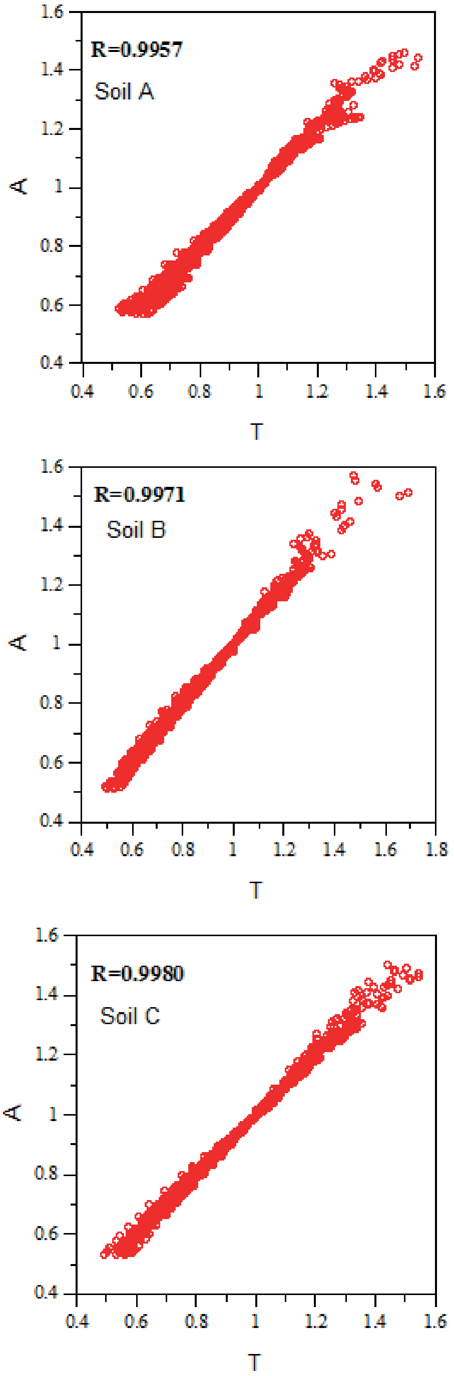

Fig. 5 Neural networks versus target DRF for different classes of sites

3.4 Correlation analysis

In order to verify the quality of the selected network (with 32 cells in the hidden layer), the entire set of data (i.e., data used for learning, validation and testing) has been passed through the network to perform a linear regression between the network outputs A and the corresponding targets T.

The correlation coefficient R allows us to measure the quality of the network prediction; a perfect prediction suggests that all the points are aligned along the diagonal A = T and the correlation coefficient is R = 1. Figure 5 represents the linear regression between the network outputs DRF and the corresponding targets DRF for all site classes. It is noticed from this figure that the fitting lines are practically superposed with the diagonal, and the correlation coefficient is very close to unity, which means that the neural network gives very accurate predictions of the damping reduction factor values.

4 Results and discussions

4.1 Relative error

The efficiency of the proposed method in this paper (ANN) is verified through the comparison with the exact mean values response spectra. In table 1, we compare the obtained DRF for both methods for some pairs of values of damping and period. A relative error through the equation 3, was calculated between the DRF obtained from both ANN and EC 8 methods, and the DRF obtained from the exact mean values response spectra and these results are presented in the following table.

$$\mathrm{ERR}_{\mathrm{ANN}}\left(\mathrm{T},\xi\right)=\left|\frac{\mathrm{DRF}_{\mathrm{real}}-\mathrm{DRF}_{\mathrm{ANN}}}{\mathrm{DRF}_{\mathrm{real}}}\right|. \tag{3}$$

We observed that the relative error committed while the use of the ANN is less than that resulted from the EC8 formulation. For instance, for $T = 8$ s and $\xi = 20$ %, we observed that the error for ANN equal to 0.2 % and 34.0 % for EC8 for soil A , 0.5% for ANN and 30.3 % for EC8 for soil B and 0.2% for ANN and 21.2 % for EC8 for soil C. It is clear from this results that the use of the ANN gives very good results comparing to EC8 formulation.

The mean of the errors obtained for $\xi = 20$ % and for all periods used for this study can be reduced too. This error is equal to 1.25% for ANN and 20.11 % for EC8 for soil A, 0.85% for ANN and 20.86 % for EC8 for soil B, and 1.07% for ANN and 13.27 % for EC8 for soil C. It is evident that the proposed method closely follows the mean values of 'exact' dynamic analysis.

The ANN constitutes a sample and efficiency method to predict the DRF, and more exact than the models obtained from the nonlinear regression.

4.2 Statistical results

The accuracy of the presented methods is examined also by the use of two statistical terms, referring to a single group of earthquakes. The considered statistical indexes are the mean spectral ratio MSR (T, ξ) and the standard error SE (T, ξ) between approximate and exact high-damping displacement response spectra. They are defined by the following expressions:

$$\mathrm{M}SR\left(T,\xi\right)=\frac{1}{n}\sum_{i=1}^{n}\frac{DRF\left(T,\xi\right)*Sd_i\left(T,\xi=5\%\right)}{Sd_i\left(T,\xi\right)} \tag{4}$$

$$SE\left(T,\xi\right)=\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\frac{DRF\left(T,\xi\right)*Sd_i\left(T,\xi=5\%\right)-Sd_i\left(T,\xi\right)}{Sd_i\left(T,\xi\right)}\right)^2} \tag{5}$$

Where Sd,i (T, ξ) is the real maximum displacement, obtained through linear time-history analysis of SDOF with vibration period T and damping ratio ξ, due to the ith seismic ground motion, DRF = DRF (T, ξ) is the damping reduction factor obtained through the method which we have to estimate its accuracy and n is the total number of ground acceleration-time histories taken into account. For the evaluation of both MSR and SE, a constant period increment of 0.05 sec has been considered.

The standard error SE measures the scattering of the approximate maximum displacements around their exact values.

Values of SE close to zero imply a good accuracy of the approximate method in the prediction of the real maximum displacements.

In the figures below, Values of MSR (T, ξ) are smaller than 1.0 indicate that the approximate method underestimates, on average, the exact maximum elastic displacement, for that period and damping ratio. And values of MSR (T, ξ) larger than 1.0 mean that the approximate method generally overestimates the exact maximum elastic displacement, for that period and damping ratio.

Equations (4) and (5) are computed for linear elastic SDOF systems with viscous damping ratios 10%, and with a set of 200 periods of vibration between 0.1 and 10 sec with an increment of 0.05 sec.

Table 4 Damping reduction factors for EC 8 and ANN

	T	ξ	exact	EC8	ANN	Error for EC8 (%)	Error for ANN (%)
Soil A	0.5	0.07	0,892	0,913	0,900	2,31	0,82
	2.0	0.10	0,839	0,817	0,846	2,71	0,85
	4.5	0.14	0,827	0,726	0,843	12,25	1,97
	8.0	0.20	0,956	0,633	0,956	33,87	0,01
Soil B	0.5	0.07	0,888	0,913	0,914	2,81	2,99
	2.0	0.10	0,854	0,817	0,853	4,44	0,12
	4.5	0.14	0,856	0,726	0,854	15,27	0,22
	8.0	0.20	0,903	0,633	0,906	29,97	0,26
Soil C	0.5	0.07	0,889	0,913	0,899	2,71	1,14
	2.0	0.10	0,817	0,817	0,827	0,09	1,18
	4.5	0.14	0,811	0,726	0,798	10,55	1,65
	8.0	0.20	0,801	0,633	0,797	21,04	0,52

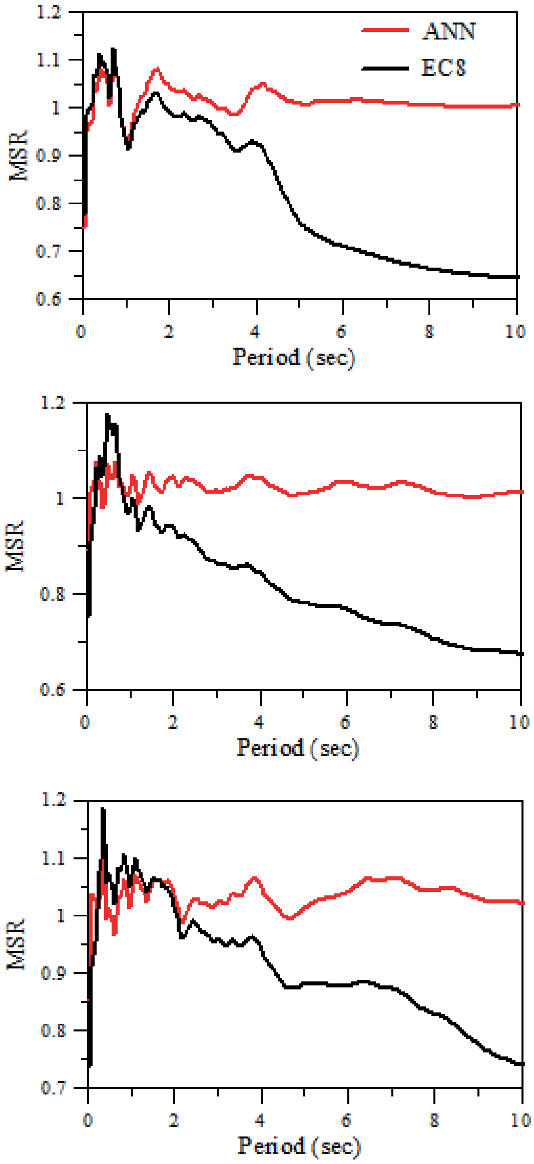

Fig. 6 mean spectral ratios for different classes of EC8

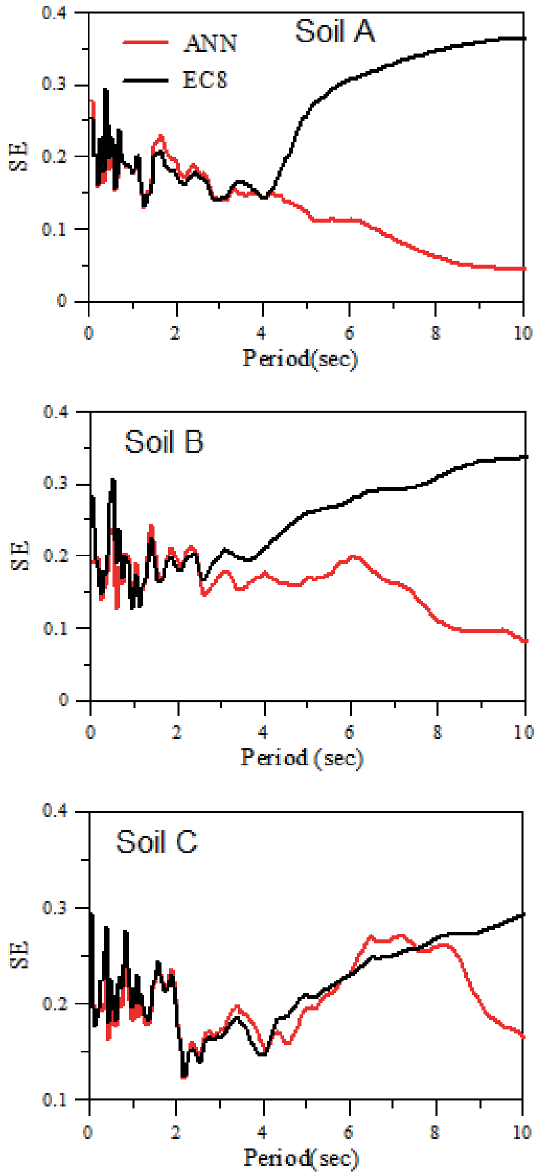

Fig. 7 Standard error of DRF for different classes of EC8

Figures 6 and 7 show the statistical terms derived from the obtained records for different soils. The following observations can be obtained:

1. The mean spectral ratio obtained by ANN has a little perturbation around the value 1. That is means that the ANN gives approximately the same values of the damping reduction actor as the values obtained through the linear time-history analysis (exact values). The results of EC8 formulation underestimate the DRF; it gives very different values than the exact values especially for $T > 2$ sec. It is clear from these results that the use of the ANN gives more exact values than EC8.

2. The graphs of The standard error SE presented at the figure 7 shows that the error committed while the use of the ANN for the computing of the DRF is less than the error committed while the use of the EC8. The graphs of the SE for the ANN are more close to zero than the graphs of EC8, especially for Soil A and B when the error for EC8 have a value greater than 0.35 while that of the ANN is less than 0.1 for $T > 4$ sec.

4.3 Comparison with literature formulation

In this section, a comparison between different approximate formulations of DRF from the literature and the DRF values obtained in this study through the ANN is presented, for different values of ξ (7, 10, 20 and 25%, respectively).

The approximate formulations of the DRF considered herein are those proposed by: (i) Bommer et al (2000) (EC8), (ii) Lin and Chang (2003), (iii) Hatzigeorgiou (2010) and (iv) Zhou et al (2003) [27].

The DRF proposed by Bommer et al. (2000) is expressed by the following formula:

$$DRF = \sqrt{\frac{10}{5+\xi}} \geq 0.55 \tag{6}$$

It has been adopted in the European seismic code (EC8 EN 2004).

Hatzigeorgiou (2010) has proposed a new method for evaluating DRF taking into account the influence of soil conditions and ground motion type (use of natural or artificial accelerograms, near- or far-fault earthquakes), besides viscous damping ratio and period of vibration:

$$DRF(\xi,T)=1+(\xi-5)\cdot\left[1+c_1\cdot\ln(\xi)+c_2\cdot(\ln(\xi))^2\right]\cdot\left[c_3+c_4\cdot\ln(T)+c_5\cdot(\ln(T))^2\right] \tag{7}$$

The values of the coefficients ci are given in (Hatzigeorgiou 2010) as a function of the soil type and the type of seismic ground motions.

Lin and Chang (2003) proposed the following period dependent formulation of DRF:

$$DRF=1-\frac{aT^{0.30}}{(T+1)^{0.65}} \tag{8}$$

where $a = 1.303 + 0.436\ln(\xi)$.

The expression proposed by Zhou et al (2003) was adopted in the Chinese code for seismic design of buildings:

$$DRF=1+\frac{0.05-\xi}{0.06+1.4\times\xi} \tag{9}$$

The comparison between the exact DRF values and the different approximate formulations of DRF and the values obtained through the ANN for four values of damping (7, 10, 20 and 25 %) is presented in fig.8. This comparison is presented only for the soil A because that all the seismic code (included the EC8) present the same formulation for all the soils type.

From the previous figures the following conclusions can be drawn:

1. The differences between the approximated DRF formulations and the exact results increase while increasing the damping ratio. This difference is increased for $T > 4$ sec, and presents a maximal value for $T = 10$ sec.
2. According to the figure, for $T < 0.7$ sec, the most important values of the DRF, ie, more conservative, are those obtained from the formulation of Hatzigeorgiou. Although, the lowest (more Nonconservative) are those provided by Zhou et al. the formula of the EC 8 overestimate the structures seismic response in this range of periods. This overestimation puts to the structures built using the values of response in the safety zone.
3. For $0.7 < T < 4$ sec, the DRF values of the EC8 are smaller than the exact results, it means that the EC8 formulation underestimates the seismic response for the structures in this range of periods. This presents a seismic risk for this structures. The formula of Lin et al constitutes a good estimator of DRF values in the range. The ANN constitutes the closest model to the exact results.
4. For $T > 4$ sec, all formulations give DRF values very smaller than the exact results. For instance, for $T = 10$, the DRF obtained through the EC8 formulation is = 0.577 and the exact values is 0, 975 while the ANN gives value DRF = 0.976. This difference, between the exact and the EC8

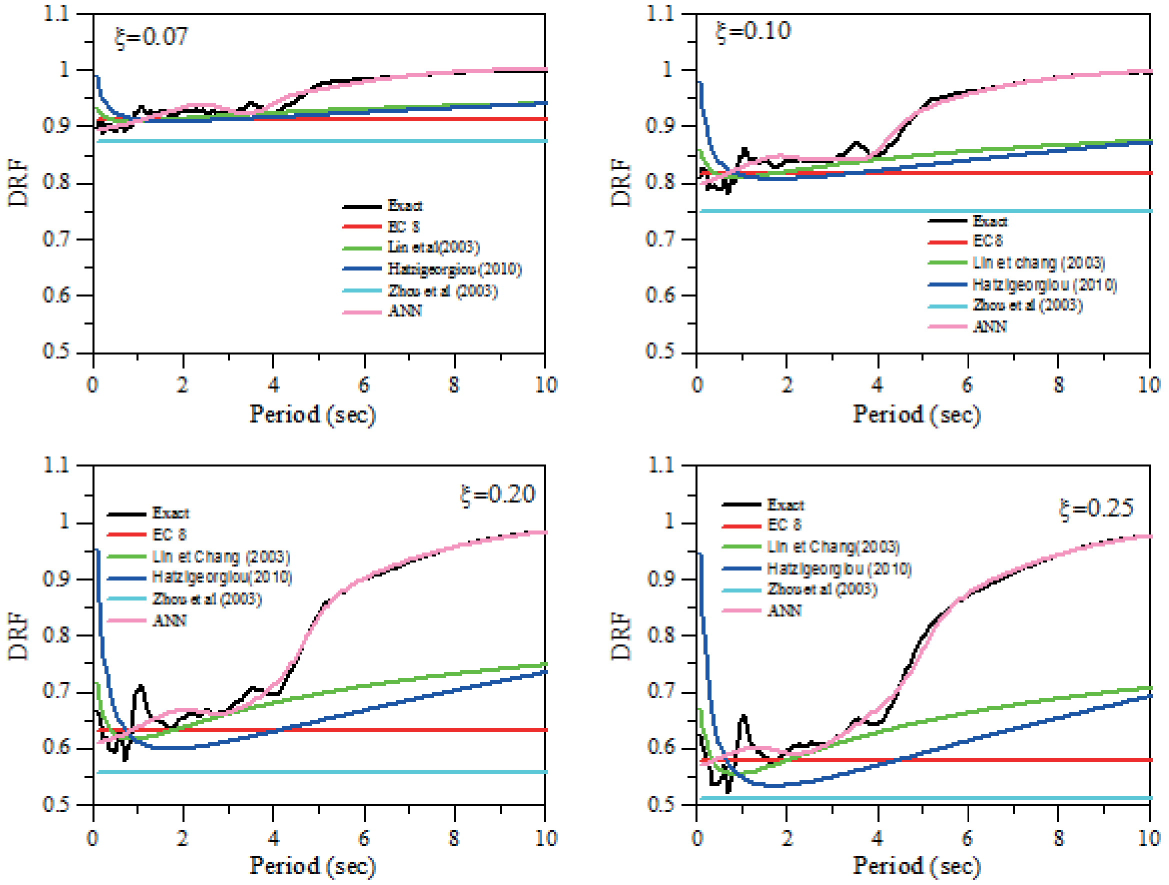

Fig. 8 Comparison between different approximate formulations of DRF and the exact values of DRF

formulation, up to 40 % means that the error for the seismic response can exceed the 40 %. This implies the importance of the problem and the damage that this error can introduced to the structure dimensioned considering a worn value of DRF (i.e a wrong value of design seism response.

5. The results obtained through the ANN method are very close to the exact results, the tow curves are practically superposed for all the periods. This provides the good approximation of the ANN and the accuracy of this method for the estimation of the DRF values.

5 Conclusions

The accuracy of the ANN for the evaluation of damping reduction factor for high damping response spectra for EC8 has been examined. The efficiency of the developed ANN procedure was examined in light of three parameters characterizing the regression analysis: the correlation coefficient R, the mean spectral ratio MSR (T, ξ) and the standard error SE (T, ξ). The obtained results corroborate for a good matching of the estimated DRF values with the exact results.

The conclusions and suggestions drawn from this study can be summarized as follows.

The relative error committed while the use of the ANN is less than that resulted from the EC8 formulation. For instance, for T= 8 s and $\xi = 20$ %, we observed that the error for ANN equal to 0.2 % and 34.0 % for EC8 for soil A , 0.5% for ANN and 30.3 % for EC8 for soil B and 0.2% for ANN and 21.2 % for EC8 for soil C. It is clear from these results that the use of the ANN gives very good results comparing to EC8 formulation.

According to the results, the DRF values of the EC8 are smaller than the exact results, it means that the EC8 formulation underestimates the seismic response for the structures in range of periods $T > 0.7$. This presents a seismic risk for these structures. For instance, for $T = 10$, the DRF obtained using the formulation of EC8 is 0.577 and the exact values is 0, 975 while the ANN gives value DRF = 0.976. This difference, between the exact and the EC8 formulation, up to 40 % means that the error for the seismic response can exceed the 40 %. This implies the importance of the problem and the damage that this error can introduce to the structure designed considering a worn value of DRF (i.e wrong value of design seismic response.

The ANN constitutes a sample and efficiency method to predict the DRF, and more exact than all formulations in literature.

The ANN can be limited when the number of inputs values is limited, it means that we can have a poor regression. The only condition to obtain good results using the ANN is to find enough records that can be representative of the selected code.

The ANN is a new and accurate method for estimating DRF values, the proposed approach is original and the associated results are interesting and promising. The developed ANN can be used to estimate the DRF for different seismic codes with a very good approximation.

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