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PROPOSAL OF A SELECTION CRITERIUM OF NATURAL ACCELEROGRAMS FOR NLRHA

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ABSTRACT

A selection criterion to obtain different sets of accelerograms, all of them satisfying the spectrum compatibility criteria imposed by the codes, that enable a reliable assessment of the seismic demand for a given structure is proposed. The formulation is based on a preliminary evaluation of correlations among Intensity Measure parameters for ground motion and cinematic, energetic and damage parameters describing structure non linear responses. To this aim, a modified expression of the Effective Peak Acceleration EPA* is proposed, defined over the range of structure fundamental period referring to undamaged and damaged model. The analyses are carried out analyzing the response of a three plane multi-storey Reinforced Concrete Moment Resisting Frames (RCMRFs) to a set of 60 different accelerograms, and analyzing the value of the correlation coefficients between input Intensity Measure and structure response parameters. Then, a new selection criterion for accelerogram sets based on the minimum value of the Coefficient of Variation (CoV) of the EPA* is proposed. Effectiveness is proved by evaluation of average values and COV of NLRHA response parameters for the RCMRFs.

INTRODUCTION

The Non Linear Response History Analysis (NLRHA) represents nowadays the more accurate method for prediction of the seismic response of structures because it takes into account in the analysis the non linear material and geometrical behaviour of the structure. In NLRHA a key issue is the input modelling, because the assessment of structure seismic demand is very sensitive to the representation of seismic action. In this context, recently the use of recorded natural accelerograms is gaining popularity because synthetic and artificial accelerograms are not able to reproduce all the characteristics of the recorded representation of the seismic action, such as the real phasing, seismic energy content and distribution, non stationarity, and so on.

Many researches were devoted to formulation of methods for selection of natural accelerograms for NLRHA (Amiri and Dana, 2004; Elenas and Meskouris, 2001; Iervolino and Cornell, 2004; Iervolino Maddaloni and Cosenza, 2006; Galasso and Iervolino, 2011). Eurocode 8 (2005) prescribes that the accelerograms must be adequately qualified with regard to the seismo-genetic features of the sources

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and to the soil conditions appropriate to the site. Moreover, they have to be selected so that in the range of periods between 0,2 T_1 and 2 T_1, where T_1 is the fundamental period of the structure in the direction where the accelerogram will be applied; no value of the mean 5% damping elastic spectrum, calculated from all time histories, should be less than 90% of the corresponding value of the 5% damping elastic response spectrum.

This condition makes it difficult the selection of the accelerograms from the available database because the spectrum compatibility condition is imposed in a wide range of period. By contrast, it is well-known that natural accelerograms are usually characterized by energy content in a more limited range of frequencies; consequently response spectra are sharp rather than smooth. Therefore, in order to obtain the imposed condition in the wide range of periods, the average spectrum is often obtained by accelerogram samples with very different intensity, that induce very different response when structures are excited in non linear field. As a result, the assessment of the seismic demand by averaging the structure response to samples of such type of record sets assumes the significance of a conventional estimation, obtained as a mathematical average of very scattered responses that are not able to represent the structure response under seismic action with intensity comparable to that of the target response spectrum.

In this context, a research aiming to find out a selection criterion for different sets of accelerograms, all of them satisfying the spectrum compatibility criteria imposed by the code, that enable a reliable assessment of the seismic demand is performed. The analysis is based on a preliminary evaluation of correlation among parameters for ground motion Intensity Measure (IM) and cinematic, energetic and damage parameters describing the structure non linear responses. To this aim, a modified expression of the Effective Peak Acceleration EPA* is proposed, defined over the range of structure fundamental period referring to undamaged and damaged model. Then the effectiveness of a selection criterion for accelerogram sets based on the minimum value of the Coefficient of Variation (CoV) of the EPA* is proved by NLRHA of the response of multi-storey Reinforced Concrete Moment Resisting Frames (RCMRFs)

SEISMIC INPUT SELECTION

The selection of natural accelerograms according to the EC8 provisions, namely compatible with the elastic response spectrum in the range [0.2 T_1-2 T_1], were performed by using the computer program REXEL v 3.2 beta (Iervolino et al., 2009), that allows one to find out many sets of natural accelerograms fulfilling the code provisions by searching in the following database: European Strong-motion Database (ESD), (http://www.isesd.cv.ic.ac.uk), l'Italian Accelerometric Archive (ITACA) (http://itaca.mi.ingv.it) and the Selected Input Motions for displacement-Based Assessment and Design (SIMBAD) database (http://wpage.unina.it/iuniervo/SIMBAD_Database_Polimi.pdf).

The code enables the evaluation of the target response spectrum according to EC8 and the new Italian code for construction NTC08 [CS.LL.PP. (2008)], allowing one to take into account the main characteristics of the site. In the following numerical analyses a target spectrum for soil type B having Peak Ground Acceleration (PGA) a_g=3,99 m/sec^2, and a value of the constant maximum pseudo-acceleration branch 9,77 m/sec^2 is assumed. Exploring the accelerogram database and limiting the research to those of the same soil class of the response spectrum (type B), in the magnitude M range $5.8<M<7.5$, and epicentral distance R in the range $0<R<30$ more than 100 sets of 14 records, which are seven 2-components recordings (for both X and Y direction) of 7 recording stations only are found. Their average response spectrum are compatible with the reference spectrum according to EC8 provisions.

Noterworthy, most of the records pertaining to the different sets are coincident, and the 100 sets are made of less than 60 different samples of accelerograms. In order to analyze the characteristic of the records, for each accelerogram the following IM parameters were evaluated:

- magnitudo M, epicentral distance R, Peak Ground Acceleration PGA, Peak Ground Velocity PGV. Moreover three other IM parameters are evaluated, namely Arias intensity I_A, , Effective Peak Acceleration EPA, and Housner index I_H, that are defined as follows:

$$I_A=\frac{\pi}{2g}\int_0^{\infty}[a(t)]^2\,dt;\ I_D=\frac{\int_0^{tf}[a(t)]^2\,dt}{PGA\ PGV};EPA=\frac{\int_{0.1}^{0.5}S_a(T)dT}{(0.5\text{-}0.1)};I_H=\int_{0.1}^{0.5}S_v(\xi=0.2,T)dT \qquad (1)$$

where $S_a(T)$ e $S_v(\xi=0.2,T)$ are the acceleration and velocity elastic response spectra for 5% and 20% of the critical damping respectively. Moreover, for each set the deviation σ_m of the average spectrum in respect to the code target spectrum were evaluated, defined as follows (Iervolino et al 2009).

$$\sigma_m=\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{Sa_m(T_i)-Sa_{target}(T_i)}{Sa_{target}(T_i)}\right)^2} \qquad (2)$$

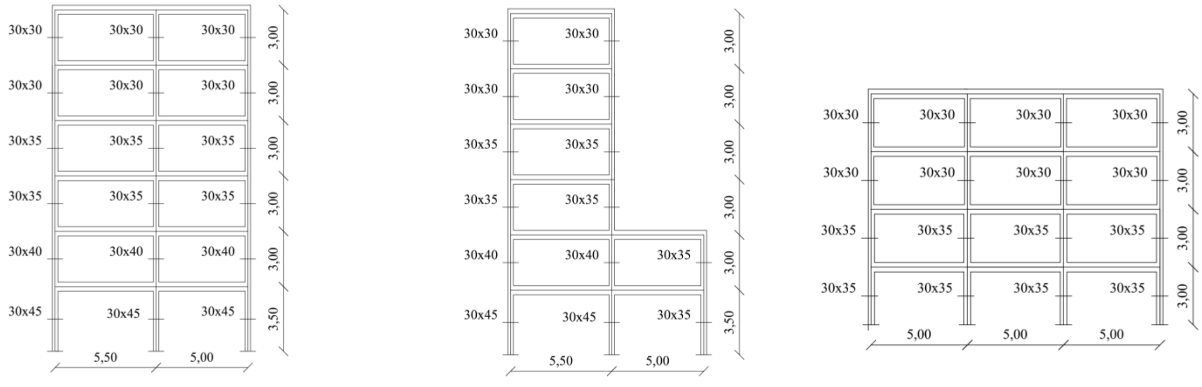
where $Sa_m(T_i)$ and $Sa_{target}(T_i)$ are the pseudo-acceleration ordinate corresponding to the period T_i of the average elastic response spectrum of the accelerogram set and of the code target spectrum respectively, and N is the sampling number of values within the considered range of periods.

In Table1 the IM parameters of the different accelerograms of the selected sets are shown. The column #REC define the label of the accelerogram in the Rexel program, the columns #X e #Y define the label given to the X and Y component of the accelerogram in the following analyses, in the other columns the values of the IM parameters of the records are shown

Table 1: Label, charatetteristic and Intensity measure parameters of the record

#REC	#X	#Y	M	R	PGA^X	PGA^Y	PGV^X	PGV^Y	I_A^X	I_A^Y	I_D^X	I_D^Y	EPA^X	EPA^Y	I_H^X	I_H^Y
42	1	2	5.80	15	5.15	2.50	0.57	0.25	1.36	0.50	0.72	1.23	9.91	5.23	1.70	0.65
55	3	4	6.50	23	3.50	3.10	0.21	0.33	0.80	1.17	1.70	1.81	7.52	7.53	0.60	0.77
74	5	6	6.70	11	6.04	7.07	0.51	0.62	4.76	4.95	2.40	1.75	11.82	12.54	1.41	1.51
126	7	8	6.00	21	4.65	4.96	0.27	0.22	0.73	1.09	0.90	1.58	9.03	10.64	0.72	0.61
146	9	10	6.00	14	3.40	3.30	0.23	0.23	0.54	0.80	1.09	1.63	6.86	7.87	0.41	0.65
182	11	12	7.30	12	3.32	3.78	0.18	0.24	1.61	1.61	4.14	2.78	7.69	7.44	0.56	0.72
196	13	14	6.90	25	4.45	3.00	0.39	0.25	4.52	1.98	4.08	4.09	11.35	7.56	1.25	0.65
197	15	16	6.90	24	2.88	2.36	0.39	0.48	1.84	1.29	2.59	1.79	6.29	4.75	0.95	1.19
199	17	18	6.90	16	3.68	3.56	0.42	0.52	1.97	3.01	1.97	2.55	5.30	8.71	1.47	1.83
291	19	20	6.90	16	1.23	1.30	0.18	0.19	0.60	0.83	4.28	5.36	3.54	4.12	0.48	0.56
334	21	22	6.60	19	2.84	1.67	0.23	0.22	0.89	0.37	2.16	1.58	6.51	3.70	0.82	0.50
413	23	24	5.90	10	2.11	2.91	0.33	0.32	0.60	0.87	1.35	1.45	5.35	8.08	0.81	0.85
414	25	26	5.90	11	2.35	2.67	0.32	0.24	0.55	0.74	1.16	1.84	6.12	7.48	0.69	0.71
535	27	28	6.60	13	3.81	5.03	1.01	0.71	1.57	1.85	0.63	0.81	7.01	9.97	1.95	1.60
594	29	30	6.00	11	5.14	4.54	0.32	0.29	3.30	2.82	3.14	3.34	11.36	12.74	0.86	0.90
879	31	32	6.40	8	2.67	3.13	0.29	0.41	1.58	1.94	3.15	2.38	7.64	8.18	0.78	1.09
1313	33	34	6.00	16	2.60	3.01	0.16	0.15	0.34	0.44	1.26	1.56	4.65	6.07	0.45	0.39
1703	35	36	7.20	8	3.70	5.04	0.36	0.65	2.58	2.72	3.05	1.29	10.68	9.77	1.07	1.47
1715	37	38	6.00	14	3.20	3.04	0.22	0.17	0.59	0.68	1.33	2.02	7.39	7.32	0.45	0.47
1726	39	40	6.30	30	2.16	2.64	0.28	0.20	0.90	1.01	2.33	2.93	5.08	5.97	0.71	0.69
4673	41	42	6.50	15	2.04	4.68	0.12	0.48	0.32	2.03	1.98	1.41	4.32	10.58	0.38	1.22
4674	43	44	6.50	5	3.12	3.31	0.61	0.24	1.24	1.24	1.02	2.45	7.96	8.28	1.20	0.78
6328	45	46	6.40	12	3.27	3.84	0.20	0.20	1.23	1.15	2.97	2.32	8.77	9.68	0.43	0.68
6332	47	48	6.40	6	5.19	5.57	0.22	0.83	1.21	1.53	1.67	0.52	10.66	8.98	0.74	1.81
6334	49	50	6.40	11	4.12	7.07	0.38	0.97	1.12	2.06	1.13	0.47	7.58	9.95	0.78	2.15
6349	51	52	6.40	5	7.30	8.22	0.46	0.92	1.65	2.74	0.78	0.56	11.46	13.41	0.99	2.02
6500	53	54	7.20	23	4.86	9.02	0.17	0.38	2.00	9.83	3.89	4.47	8.99	20.20	0.53	1.00
7142	55	56	6.30	14	5.05	2.92	0.34	0.21	1.99	0.82	1.83	2.09	11.32	6.46	0.95	0.51
7329	57	58	6.10	11	4.12	3.75	0.28	0.35	1.39	1.13	1.89	1.34	8.28	7.45	0.95	0.98

STRUCTURE MODELS FOR NLRHA



6SR 6SIR 4SR

Figure 1. Structure models for Non-Linear Response History Analysis

In Figure1 the schemes of the three RCMRFs used for the NLRHA are shown. In the 6 Storeys Regular Frame (6SRF) and in the 6 Story Irregular Frame (6SIRF) the column of the first and second story have longitudinal rebars with diameter ϕ=16 mm, with three bars placed along the longer side, while the column of the 3 to 6 storey are arranged with 4 ϕ16. In the 4 Story Regular Frame (4SRF) al the columns are reinforced with 4 rebar of diameter ϕ16. All the beams of the three frames carry a dead +live load of 20 kN/m and have cross-section of 30x50 cm. The beam end sections are reinforced with 2Φ14+2Φ18 rebar at the upper chord and 2Φ18 rebar at the bottom chord; all rebar are of grade 380. The seismic behaviour of all these three structures have been evaluated by NLRHA, by assuming a concentrated plastic hinge model for beams and a fiber model for columns. For the steel of rebar, a bilinear stress-strain relationship with hardening was assumed, characterized by a yielding and ultimate strength of f_{yk}=395 MPa and f_{su}=500 MPa respectively. The unconfined concrete has a cylindrical strength f_{ck}=30 MPa in the 6 story frames and f_{ck}=25 MPa in the 4 story frame. The confined and unconfined concrete behaviour was modelled according to Saatcioglu and Razvi (1992). The first three structure period of vibration T_1, T_2, and T_3 are 1.06 s, 0.365 s and 0.21 s for 6SRF, 0.98 s, 0.38 s, and 0.22 s for the 6SIRF, and 0.50 s, 0.17 s and 0.10 s for the 4SRF.

In order to obtain an assessment of the strength and displacement capacities of the structures, the seismic behaviour of each structure was investigated by push-over analysis, by assuming a “triangular” shape of the seismic force. The yielding and ultimate rotation of the plastic hinge were evaluated on the basis of the following expressions of yielding φ_y and ultimate φ_u curvatures and plastic hinge length L_{pl}:

$$\vartheta_y = \varphi_y \frac{L_V}{3} + 0,0013\left(1+1,5\frac{h}{L_V}\right) + 0,13\varphi_y \frac{d_b f_y}{\sqrt{f_{ck}}} \tag{3a}$$

$$\vartheta_u = \frac{1}{\gamma_{el}} \cdot [\vartheta_y + \left(\varphi_u - \varphi_y\right) \cdot L_{pl} \cdot \left(1 - 0,5\frac{L_{pl}}{L_v}\right) \tag{3b}$$

$$L_{pl} = 0.1 \cdot L_V \cdot + 0.17h + 0.24\frac{d_b\ f_{yk}}{\sqrt{f_{ck}}} \tag{3c}$$

where L_V is the shear length, h is the section height, d_b is the mean diameter of the longitudinal rebar, and $\gamma_{el} = 1,5$.

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Table 2: Ultimate, yielding displacements (mm), available ductility and base shear (kN)

	6SRF				6SIRF				4SRF			
	x_u	x_y	μ	F_y	x_u	x_y	μ	F_y	x_u	x_y	μ	F_y
Structure	33.56	8.51	3.94,	25484	31.29	9.07	3.45	17997	18.01	4.48	4.02	46336

In Table 2 the values of the yielding x_y and ultimate x_u displacements, available ductility μ and yielding base shear F_y of the three structures are shown.

ACCELEROGRAMS SELECTION CRITERIA

Each selected record was used as input in the NLRHA of the response of the three frames. The numerical analyses initially aim to investigate the correlation between the IM parameters of the input and the structure non linear response. The latter is here described by cinematic, energetic and damage parameters, namely the displacement ductility demand μ, energetic ductility demand μ_{EH} and the Park & Ang index $I_{P\&A}$ defined as follows

$$\mu = \frac{x_{max}}{x_y}; \quad \mu_{EH} = \frac{E_H}{F_y x_u}; \quad I_{P\&A} = \frac{x_{max}}{x_u} + \beta \cdot \mu_{EH} \tag{4}$$

where E_H is the structure energy dissipated by plastic deformation and β a numerical parameter assumed equal to a 0,15. In order to selected the input characteristic parameters that are more effective for prediction of the effects induced by the input on the structure non linear response, so that they can be utilized for selection of natural accelerogram for NLRHA, the correlation coefficients of the structure response $x_{1,}$, and characteristic parameters of the registration x_2 are evaluated, as Peak Ground Acceleration PGA, Peak Ground Velocity PGV, Arias intensity I_A, Effective Peak Acceleration EPA, and Housner index I_H, together with the elastic response spectra ordinate $S_e(T_i)$ (i=1,2).

Among the characteristic parameters of the natural accelerograms able to represent the expected effects on a structure having vibration periods of the first two modes T_1 e $T_{2,}$ the value of a modified expression of the effective Peak ground Acceleration $EPA^*(T_i,T_i^d)$ (i=1,2) has been evaluated (Colajanni, 1999). $EPA^*(T_i,T_i^d)$ is defined as follows:

$$EPA^*(T_i, T_i^d) = \frac{\int_{T_i}^{T_i^d} Se(T)dT}{\int_{T_i}^{T_i^d} Se(T)^{target} dT / a_g^{target}} \tag{5}$$

$EPA^*(T_i,T_i^d)$ is evaluated in the period range that refers to the i^{th} vibration mode of the structure between the period in the elastic condition T_i and that corresponding to expected damaged state of the structure T_i^d. The latter could be evaluated depending on the behaviour factor value that is related to the ratio between the structure strength and the seismic excitation intensity according to Colajanni *et al.* (2013) or simpler by an enlarged value of T_i. The following results are obtained by assuming T_{id}=1.5 T_i.

In Table 3 the values of correlation coefficients between input and structure response characteristic parameters are shown for the three analyzed frames

The values in Table 3 show that the parameters affect by the greater correlation between input IM parameters and structure response are the modified Effective Peak ground Acceleration of the first mode $EPA^*(T_1,T_1^d)$ and the Housner index I_H; while the Peak Ground Velocity PGV has a large correlation with the displacement ductility demand only, and small correlation with energy ductility demand and the Park & Hand damage index

Table 3: Correlation coefficents for input record and structure response parameters

	6SRF			6SIRF			4SRF		
	μ	μ_{EH}	$I_{P\&A}$	μ	μ_{EH}	$I_{P\&A}$	μ	μ_{EH}	$I_{P\&A}$
PGA	0.42	0.22	0.38	0.36	0.22	0.34	0.52	0.16	0.46
PGV	0.91	0.67	0.89	0.84	0.59	0.82	0.76	0.22	0.66
I_A	0.22	0.36	0.28	0.19	0.52	0.29	0.39	0.75	0.57
I_D	0.48	0.21	0.42	0.45	0.06	0.37	0.32	0.41	0.10
EPA	0.27	0.17	0.26	0.22	0.22	0.23	0.45	0.38	0.48
$S_e(T_1)$	0.76	0.81	0.81	0.77	0.87	0.84	0.56	0.58	0.63
$S_e(T_2)$	0.08	0.05	0.07	0.10	0.20	0.13	0.34	0.04	0.28
$EPA^*(T_1,T_1^d)$	0.88	0.93	0.95	0.88	0.90	0.93	0.68	0.86	0.83
$EPA^*(T_2,T_2^d)$	0.25	0.14	0.23	0.22	0.29	0.25	0.23	0.22	0.26
I_H	0.92	0.79	0.93	0.87	0.77	0.90	0.85	0.46	0.82

Table 4: Correlation coefficents for input record and response parameters of the roof (6th storey)

ρ (input-6th storey)	Regular 6 store			Irregular 6 store			Regular 4 store		
	μ	μ_{EH}	$I_{P\&A}$	μ	μ_{EH}	$I_{P\&A}$	μ	μ_{EH}	$I_{P\&A}$
PGA	0.44	0.33	0.44	0.31	0.32	0.31	0.45	0.44	0.66
PGV	0.18	0.04	0.18	0.03	0.08	0.03	0.23	0.18	0.23
I_A	0.45	0.56	0.46	0.38	0.73	0.40	0.31	0.20	0.30
I_D	0.01	0.24	0.02	0.12	0.33	0.14	0.34	0.35	0.34
EPA	0.55	0.50	0.55	0.47	0.56	0.48	0.61	0.47	0.61
$S_e(T_1)$	0.18	0.14	0.18	0.18	0.22	0.19	0.35	0.27	0.35
$S_e(T_2)$	0.70	0.65	0.71	0.70	0.78	0.71	0.67	0.63	0.67
$EPA^*(T_{1,}T_1^d)$	0.02	0.06	0.02	0.07	0.02	0.07	0.31	0.16	0.30
$EPA^*\ (T_{2,}T_2^d)$	0.57	0.60	0.57	0.45	0.68	0.47	0.66	0.63	0.66
I_H	0.23	0.12	0.23	0.03	0.17	0.04	0.19	0.11	0.19

Table 5. Coefficient of Variation of Characteristic input Parameters for different sets (referred to the three analysed structures)

COV	**Minimum COV**										**Maximum COV**									
Structure	**Regular 6 s**				**Irregular 6 s**			**Regular 4** s			**Regular 6 s**			**Irregular 6 s**			**Regular 4 s**			
Set	**8**	**14**	**19**	**23**	**8**	**14**	**81**	**8**	**43**	**83**	**60**	**75**	**95**	**53**	**60**	**95**	**28**	**60**	**74**	**95**
PGV	.38	.45	.50	.50	38	.45	.48	.38	.52	.43	.54	.51	.52	.47	.54	.52	.51	.54	.48	.52
$S_e(T_1)$	.46	.44	.55	.51	.40	.35	.45	.32	.35	.29	.60	.63	.62	.51	.53	.59	.35	.36	.43	.39
$S_e(T_2)$	.31	.27	.30	.25	.31	.28	.26	.50	.35	.50	.34	.31	.49	.41	.36	.56	.56	.40	.45	.45
$EPA^*(T_1,T_1^d)$	.47	.53	.59	.58	.44	.48	.52	.26	.37	.26	.66	.64	.65	.58	.63	.62	.31	.39	.39	.43
$EPA^*(T_2,T_2^d)$	.29	.30	.28	.30	.30	.31	.28	.34	.21	.38	.34	.37	.41	.41	.34	.40	.37	.27	.33	.36
I_H	.32	.35	.39	.36	.32	.35	.35	.32	.41	.34	.46	.44	.41	.42	.46	.41	.37	.46	.42	.41

It is noteworthy that the global response parameters do not give information about the demand distribution along the structure height, and the possible dependence of local demand by the response of the higher mode. Therefore, the correlation among the input Intensity Measure (IM) and the response parameters of the upper floor were evaluated, because a dependence from input spectral characteristic corresponding to the second period of vibration T_2 are expected.

The results shown in Table 4 stress that, as expected, the parameters that is affected by the greatest correlation is the spectral value at the second period of vibration $S_e(T_2)$, while the new effective peak acceleration at $T_{2,}$ namely $EPA^*(T_2,1.5\ T_2)\ S_e(T_2)$, has a smaller correlation because the level of non-linearity of the response of the upper story is small.

The most suitable set among the 100 sets provided by the Rexel program is chosen as that formed by accelerograms that individually represent the seismic intensity consistent with the target response spectrum. Thus, the sets affected by the smallest value of the Characteristic Parameter Coefficient of Variation (CPCoV) of the records for the parameters that have larger correlations with the structure response are selected, namely those that have the smallest Coefficient of Variation (CoV) values of PGV, I_H, $S_e(T_1)$, $S_e(T_2)$, $EPA^*(T_1,T_1^d)$ ed $EPA^*(T_2,T_2^d)$. The structural response parameters corresponding to these record sets are now compared with those of the sets that have the larger CPCoV values, and that obtained by modeling the input with the set having the smallest deviation of the average spectrum in respect to the code target spectrum σ_m (Iervolino et al.,2009). In Table 5 the values of the CPCoV of the chosen records are shown, high-lightening with the grey color the sets that for each structure are affected by the smallest and the largest values of the CPCoV

The results show that the set n°8 is affected by the minimum values of the CoV of the three input parameters EPA$^*(T_1,T_1^d)$, PGV and I_H that have the largest correlation with the structural response, while set n°60 is affected by the maxima values. However, the minimum values of the CPCoV are still large, proving anyway a great scattering of the input damage potential. Moreover the large difference between maximum and minimum CoV values for the different sets proves that this parameter is very sensitive to the set selection criterion.

EFFICENCY OF SELECTION CRITERIA

In Tables 6 and 7 for the three analyzed structure the mean and the CoV of the structure global response parameters are shown, respectively. It is noteworthy that, according to the static response parameters shown in Table 2, the three analyzed structure 6SR, 6SIR e 4SR are affected by a available ductility μ of 3.94, 3.45 e 4.02 respectively. The mean values of the ductility demand arising from the dynamic analyses shows that the input intensity is small compared to the capacity of the structures (40% for regular and 50% for the irregular frames). Moreover, comparison of the results obtained for the two set groups shows that the use of sets affected by smaller value of the CoV of the input IM lead to assessment of lightly smaller values of mean of displacement ductility demand μ_d and lightly larger values of mean of energy ductility demand μ_{EH} and of Park & Ang index than those obtained by accelerogram sets affected by the larger CPCoV.

Table 6. Mean values of structure response parameters

Mean	Mean values for sets with Minimum COV										Mean values for sets with Maximum COV									
Struct	Regular 6 s				Irregular 6 s			Regular 4 s			Regular 6 s			Irregular 6 s			Regular 4 s			
Set	**8**	**14**	**19**	**23**	**8**	**14**	**81**	**8**	**43**	**83**	**60**	**75**	**95**	**53**	**60**	**95**	**28**	**60**	**74**	**95**
μ	1.70	1.70	1.73	1.81	1.74	1.73	1.73	1.66	1.58	1.61	1.80	1.65	1.73	1.59	1.84	1.72	1.64	1.72	1.70	1.69
μ_{EH}	0.84	0.71	0.74	0.71	0.94	0.78	0.72	0.68	0.72	0.69	0.74	0.74	0.69	0.95	0.81	0.81	0.70	0.67	0.74	0.68
$I_{P\&A}$	0.56	0.54	0.55	0.57	0.71	0.68	0.67	0.52	0.50	0.50	0.57	0.53	0.54	0.66	0.73	0.69	0.51	0.53	0.53	0.52

Table 7. CoV of structure response parameters

COV	CoV for sets with Minimum CoV										CoV for sets with Maximum CoV									
Struct	Regular 6 s				Irregular 6 s			Regular 4 s			Regular 6 s			Irregular 6 s			Regular 4 s			
Set	**8**	**14**	**19**	**23**	**8**	**14**	**81**	**8**	**43**	**83**	**60**	**75**	**95**	**53**	**60**	**95**	**28**	**60**	**74**	**95**
μ	.36	.44	.58	.57	.31	.38	.52	.30	.41	.33	.66	.59	.64	.44	.66	.62	.38	.50	.46	.47
μ_{EH}	.78	.89	.90	.86	.68	.73	.80	.63	.72	.63	.93	.89	.89	.73	.82	.81	.78	.78	.79	.84
$I_{P\&A}$	.42	.49	.61	.60	.37	.41	.54	.34	.43	.37	.68	.62	.67	.49	.66	.61	.41	.50	.47	.48

Table 8. Mean values of structure response parameters for accelerogram sets chosen according σ_m

		MEAN			COV		
	Struct/Par.	Regular 6 s	Irregular 6 s	Regular 4 s	Regular 6 s	Irregular 6 s	Regular 4 s
SET 24	**μ**	1.66	1.65	1.65	0.46	0.38	0.31
	μ_{EH}	0.76	0.89	0.75	0.85	0.72	0.73
	$I_{P\&A}$	0.54	0.68	0.52	0.51	0.43	0.36
SET 14	**μ**	1.70	1.73	1.73	0.44	0.38	0.38
	μ_{EH}	0.71	0.78	0.58	0.89	0.73	0.57
	$I_{P\&A}$	0.54	0.68	0.52	0.49	0.41	0.38
SET 87	**μ**	1.73	1.76	1.76	0.52	0.57	0.48
	μ_{EH}	0.64	0.74	0.69	0.85	0.79	0.79
	$I_{P\&A}$	0.54	0.69	0.54	0.55	0.56	0.47

The results in Table 7 show that choosing the accelerogram set affected by CoV minimum values for the parameters EPA$^*(T_1,T_1^d)$, PGV, I_H lead to obtain set of response parameters affected by the minimum CoV, with CoV of displacement ductility demand reduced around 30%, while the assessment of Energy ductility demand and Park &Ang damage index is still affected by large values of the CoV. In Table 8 the mean and CoV values for the response parameters are shown, obtained by choosing the accelerogram set affected by the minimum value of σ_m (set 24), by the minimum value of the square root of sum of square of the difference between the elastic response spectrum for each accelerograms and the target spectrum (set 14), and by the minimum value of the sum of the largest difference between the spectrum of each accelerograms and the target spectrum (set 87). The results prove that none of these criteria are able to ensure a reduction of the CoV of the response parameters (displacement and energetic ductility or damage index) as large as that obtained by the accelerogram set choice criteria based on the minimum value of the CoV of the selected IM.

The following analysis aims at discussing in more detail how the seismic demand is assessed, both when a moderate or a high input intensity is considered, in comparison to the structure capacity. To this aims, results of NLRHA are presented corresponding to the level of the excitation of the previous considered accelerograms (moderate intensity), while to elucidate the structure behavior when the seismic excitation has intensity able to produce the attainement of the collapse limit state, the accelerograms are scaled by a factor two (PGA of the target spectrum a_g=7,98 m/sec^2).

In order to explicate what are the consequence of the choice of a set of accelerograms affected by a large value of the CPCoV, producing a large scattering of the sample of the response parameters, in the following Tables 9-15 for each of the three considered frames and for the two aforementioned levels of the seismic excitations, the values of the response parameters to each of the accelerograms of the previous considered sets are reported. Namely, sets affected by the minimum and the maximum values of the CoV of EPA*(T$_1$,T$_1^d$), PGV, I$_{H,}$ are considered, i.e. set n° 8 and 60 for the 6-storeys frames, and set n° 8 and 95 for the 4-storeys frame. Moreover, the correspondent values of the response parameters for set n° 24, 14, and 87 chosen according the criteria previously mentioned are reported.

Firstly, it can be recognized that the considered sets contain many common accelerograms. As matter of fact 4 accelerograms are common to the three chosen sets, and for instance referring to the 6-storey frames, 6 accelerograms are common to sets n° 8 and n°60, 6 to sets n°60 and N°24 and 10 common to set n°8 and 24.

Referring to the input with high intensity level and therefore high damage potential, for all the three chosen sets the mean value of the ductility demand is smaller than the available ductility. However, for the set n°60, for 5 accelerograms the ductility demand is larger than the capacity for the structure 6SR and 6SIR;moreover, let us stress that in 3 cases the ductility demand is larger than 150% of the capacity; these results are not able to represent the behavior of the structure excited by the input represented by the target response spectrum, and the values of the response parameters are largely dependent on the modeling of plastic hinge behavior beyond the conventional collapse; in this paper the behavior is extrapolated, assuming a residual bending capacity of the plastic hinge after the collapse equal to bending strength at the ultimate rotation; however the assessment of the ductility demand would have been much much more larger if a fragile behavior of the plastic hinge would been assumed. Therefore, the assessment of a mean value of the ductility demand obtained by means of response samples that have maximum values of local ductility demand much larger than the capacity is affected by a large level of uncertainty.

This unfavorable circumstance is restricted in set n°8, where for the three different analyzed frames, only in 3 cases for the structure 6SR and 4 in four cases for the 6SIR frame the ductility demand overcomes the capacity, and only for one accelerogram for 6SR frame and for two accelerograms for 6SIR frame the ductility demand is larger than 150% of the capacity. According to this point of view, set 24 is more performing than set 60, but the solution based on the minimum CoV values of the three input characteristic parameters EPA*(T$_1$,T$_1^d$), PGV, I$_H$ is unquestionably the most performing. Analogous conclusion can be derived by comparison of the results for the 4SR frame.

When the collapse is detected by the Park & Ang Index overcoming 1, the structure collapse is assessed for value of the PGA smaller than that previously mentioned (a_g=7,98 m/sec^2) and the above consideration should been ephasized.

Referring to the results in Table 12 to 15, that describe the structure response to input of low intensity (a_g=3,99 m/sec^2) can be recognized that in set n°60, 5 accelerograms push the structure in the elastic field only (μ<1); the same circumstance happens for 4 accelerograms of the set n°95 for 4SR frame. Equally, when the set n°24 chosen on the basis of the smaller value of σ_m is considered, the accelerograms that push the structure in the elastic field only is slightly reduced only, as proved by the circumstance that 4 accelerograms push the frame 6SR in the elastic field, and two the structures 6SIR and 4SR. Let us stress that, when the structure is pushed in the elastic field only, the main characteristic of the non linear response and the distribution of the element strength in the structure are not efficiently tested. Therefore, the assessment of the seismic demand obtained as the average of structure response both significantly in the non linear field and in the elastic state is not effective in represent the structure response at a moderate seismic excitation that exceeded the elastic capacity of the structure.

These conclusion are emphasized by comparison of the distribution of ductility demand and damage in the resistant elements of the structure that here is not reported for brevity constrain, related to the predictable concentration of ductility demand in the weaker storey.

Table 9. Six-storeys regular frame global response for high input intensity (a_g=7,98 m/sec^2)

SET 8	31	32	35	36	51	52	23	24	17	18	57	58	5	6	Mean	COV
μ	2.03	2.75	2.37	4.75	1.86	7.63	2.31	3.05	3.57	5.77	2.22	2.81	3.31	4.18	3.47	0.47
μ_{EH}	2.16	5.69	3.16	5.54	0.69	4.49	1.16	1.17	4.14	5.49	0.78	0.67	3.33	3.59	3.01	0.63
$I_{P\&A}$	0.84	1.55	1.07	2.04	0.57	2.61	0.76	0.95	1.53	2.29	0.68	0.81	1.34	1.60	1.33	0.48
SET 60	31	32	35	36	51	52	13	14	27	28	49	50	9	10	Mean	COV
μ	2.03	2.75	2.37	4.75	1.86	7.63	2.48	1.47	8.73	5.16	1.87	5.73	0.85	1.41	3.50	0.71
μ_{EH}	2.16	5.69	3.16	5.54	0.69	4.49	3.28	0.82	5.44	3.69	0.53	3.26	0.14	0.45	2.81	0.72
$I_{P\&A}$	0.84	1.55	1.07	2.04	0.57	2.61	1.12	0.50	3.03	1.86	0.55	1.94	0.24	0.43	1.31	0.67
SET 24	31	32	47	48	51	52	13	14	17	18	57	58	5	6	Mean	COV
μ	2.03	2.75	1.36	6.37	1.86	7.63	2.48	1.47	3.57	5.77	2.22	2.81	3.31	4.18	3.41	0.56
μ_{EH}	2.16	5.69	0.46	3.70	0.69	4.49	3.28	0.82	4.14	5.49	0.78	0.67	3.33	3.59	2.81	0.66
$I_{P\&A}$	0.84	1.55	0.42	2.17	0.57	2.61	1.12	0.50	1.53	2.29	0.68	0.81	1.34	1.60	1.29	0.55
SET 14	31	32	35	36	51	52	47	48	1	2	57	58	5	6	Mean	COV
μ	2.03	2.75	2.37	4.75	1.86	7.63	1.36	6.37	4.11	1.91	2.22	2.81	3.31	4.18	3.40	0.54
μ_{EH}	2.16	5.69	3.16	5.54	0.69	4.49	0.46	3.70	1.77	0.50	0.78	0.67	3.33	3.59	2.61	0.72
μ	0.84	1.55	1.07	2.04	0.57	2.61	0.42	2.17	1.31	0.56	0.68	0.81	1.34	1.60	1.25	0.54
SET 87	13	14	35	36	43	44	47	48	1	2	49	50	5	6	Mean	COV
μ	2.48	1.47	2.37	4.75	4.52	1.87	1.36	6.37	4.11	1.91	1.87	5.73	3.31	4.18	3.31	0.50
μ_{EH}	3.28	0.82	3.16	5.54	2.07	0.97	0.46	3.70	1.77	0.50	0.53	3.26	3.33	3.59	2.36	0.66
μ	1.12	0.50	1.07	2.04	1.46	0.62	0.42	2.17	1.31	0.56	0.55	1.94	1.34	1.60	1.19	0.51

Table 10. Six-storeys irregular frame global response for high input intensity (a_g=7,98 m/sec^2)

SET 8	31	32	51	52	35	36	23	24	57	58	17	18	5	6	Mean	COV
μ	2.13	3.34	1.88	6.78	2.74	3.98	1.96	3.18	2.15	2.64	3.38	5.58	3.40	4.40	3.40	0.42
μ_{EH}	2.75	6.15	1.29	5.29	4.06	6.75	1.56	1.56	1.59	1.11	5.74	7.40	4.24	4.77	3.87	0.57
$I_{P\&A}$	1.11	2.02	0.81	3.02	1.51	2.32	0.88	1.28	0.94	1.03	1.97	2.94	1.75	2.16	1.70	0.44
SET 60	31	32	51	52	35	36	13	14	27	28	49	50	9	10	Mean	COV
μ	2.13	3.34	1.88	6.78	2.74	3.98	2.44	1.40	8.58	4.30	1.67	7.06	0.97	1.47	3.44	0.69
μ_{EH}	2.75	6.15	1.29	5.29	4.06	6.75	5.91	1.97	6.07	4.05	0.51	4.29	0.28	0.85	3.59	0.64
$I_{P\&A}$	1.11	2.02	0.81	3.02	1.51	2.32	1.69	0.75	3.73	2.02	0.63	2.96	0.36	0.61	1.68	0.62
SET 24	31	32	51	52	47	48	13	14	57	58	17	18	5	6	Mean	COV
μ	2.13	3.34	1.88	6.78	1.36	5.56	2.44	1.40	2.15	2.64	3.38	5.58	3.40	4.40	3.32	0.51
μ_{EH}	2.75	6.15	1.29	5.29	0.72	4.09	5.91	1.97	1.59	1.11	5.74	7.40	4.24	4.77	3.79	0.58
$I_{P\&A}$	1.11	2.02	0.81	3.02	0.56	2.44	1.69	0.75	0.94	1.03	1.97	2.94	1.75	2.16	1.66	0.49
SET 14	31	32	51	52	35	36	1	2	57	58	47	48	5	6	Mean	COV
μ	2.13	3.34	1.88	6.78	2.74	3.98	4.72	1.87	2.15	2.64	1.36	5.56	3.40	4.40	3.35	0.47
μ_{EH}	2.75	6.15	1.29	5.29	4.06	6.75	2.55	0.71	1.59	1.11	0.72	4.09	4.24	4.77	3.29	0.62
μ	1.11	2.02	0.81	3.02	1.51	2.32	1.93	0.72	0.94	1.03	0.56	2.44	1.75	2.16	1.59	0.47
SET 87	43	44	13	14	35	36	1	2	49	50	47	48	5	6	Mean	COV
μ	3.69	1.33	2.44	1.40	2.74	3.98	4.72	1.87	1.67	7.07	1.36	5.56	3.40	4.40	3.26	0.54
μ_{EH}	2.45	0.80	5.91	1.97	4.06	6.75	2.55	0.71	0.51	4.29	0.72	4.09	4.24	4.77	3.13	0.65
μ	1.58	0.56	1.69	0.75	1.51	2.32	1.93	0.72	0.63	2.96	0.56	2.44	1.75	2.16	1.54	0.51

Table 11. Four-storeys regular frame global response for high input intensity (a_g=7,98 m/sec^2)

SET 8	31	32	51	52	17	18	5	6	57	58	35	36	23	24	Mean	COV
μ	1.52	2.66	2.45	7.08	4.55	5.14	3.83	4.79	2.62	2.63	3.65	4.73	1.91	3.40	3.64	0.41
μ_{EH}	2.12	2.78	1.34	3.58	5.08	6.67	4.81	3.36	1.75	1.30	3.45	4.94	0.82	1.32	3.09	0.57
$I_{P\&A}$	0.70	1.08	0.81	2.30	1.89	2.28	1.67	1.69	0.91	0.85	1.43	1.92	0.60	1.04	1.37	0.43
SET 95	43	44	51	52	17	18	1	2	27	28	13	14	53	54	Mean	COV
μ	2.58	1.53	2.45	7.08	4.55	5.14	7.73	2.41	9.79	3.37	3.51	1.98	1.07	1.80	3.93	0.67
μ_{EH}	1.24	0.82	1.34	3.58	5.08	6.67	2.29	1.02	4.40	2.72	6.29	2.43	0.38	3.72	3.00	0.68
$I_{P\&A}$	0.83	0.50	0.81	2.30	1.89	2.28	2.26	0.75	3.09	1.25	1.82	0.86	0.32	1.01	1.43	0.59
SET 24	31	32	51	52	17	18	5	6	57	58	13	14	47	48	Mean	COV
μ	1.52	2.66	2.45	7.08	4.55	5.14	3.83	4.79	2.62	2.63	3.51	1.98	1.48	6.26	3.61	0.48
μ_{EH}	2.12	2.78	1.34	3.58	5.08	6.67	4.81	3.36	1.75	1.30	6.29	2.43	0.84	3.40	3.27	0.57
$I_{P\&A}$	0.70	1.08	0.81	2.30	1.89	2.28	1.67	1.69	0.91	0.85	1.82	0.86	0.49	2.07	1.39	0.46
SET 14	31	32	51	52	1	2	5	6	57	58	35	36	47	48	Mean	COV
μ	1.52	2.66	2.45	7.08	7.73	2.41	3.83	4.79	2.62	2.63	3.65	4.73	1.48	6.26	3.85	0.52
μ_{EH}	2.12	2.78	1.34	3.58	2.29	1.02	4.81	3.36	1.75	1.30	3.45	4.94	0.84	3.40	2.64	0.51
μ	0.70	1.08	0.81	2.30	2.26	0.75	1.67	1.69	0.91	0.85	1.43	1.92	0.49	2.07	1.35	0.46
SET 87	43	44	49	50	1	2	5	6	13	14	35	36	47	48	Mean	COV
μ	2.58	1.53	2.65	9.61	7.73	2.41	3.83	4.79	3.51	1.98	3.65	4.73	1.48	6.26	4.05	0.59
μ_{EH}	1.24	0.82	0.56	3.18	2.29	1.02	4.81	3.36	6.29	2.43	3.45	4.94	0.84	3.40	2.76	0.64
μ	0.83	0.50	0.74	2.87	2.26	0.75	1.67	1.69	1.82	0.86	1.43	1.92	0.49	2.07	1.42	0.52

Table 12.Six storeys regular frame global response for moderate input intensity (a_g=3.99 m/sec^2)

SET 8	31	32	35	36	51	52	23	24	17	18	57	58	5	6	Mean	COV
μ	0.99	1.50	1.47	2.04	0.92	3.25	1.23	1.90	1.93	2.39	1.20	1.39	1.91	1.70	1.70	0.36
μ_{EH}	0.19	1.66	0.65	1.79	0.10	1.46	0.39	0.32	1.40	1.69	0.11	0.19	1.05	0.71	0.84	0.78
$I_{P\&A}$	0.28	0.63	0.47	0.79	0.25	1.04	0.37	0.53	0.70	0.86	0.32	0.38	0.64	0.54	0.56	0.42
SET 60	31	32	35	36	51	52	13	14	27	28	49	50	9	10	Mean	COV
μ	0.99	1.50	1.47	2.04	0.92	3.25	1.54	0.71	4.29	2.07	1.09	3.91	0.53	0.92	1.80	0.66
μ_{EH}	0.19	1.66	0.65	1.79	0.10	1.46	0.76	0.03	1.63	0.78	0.06	1.23	0.02	0.05	0.74	0.93
$I_{P\&A}$	0.28	0.63	0.47	0.79	0.25	1.04	0.50	0.18	1.33	0.64	0.29	1.18	0.14	0.24	0.57	0.68
SET 24	31	32	47	48	51	52	13	14	17	18	57	58	5	6	Mean	COV
μ	0.99	1.50	0.94	2.88	0.92	3.25	1.54	0.71	1.93	2.39	1.20	1.39	1.91	1.70	1.66	0.46
μ_{EH}	0.19	1.66	0.06	1.27	0.10	1.46	0.76	0.03	1.40	1.69	0.11	0.19	1.05	0.71	0.76	0.85
$I_{P\&A}$	0.28	0.63	0.25	0.92	0.25	1.04	0.50	0.18	0.70	0.86	0.32	0.38	0.64	0.54	0.54	0.51
SET 14	31	32	35	36	51	52	47	48	1	2	57	58	5	6	Mean	COV
μ	0.99	1.50	1.47	2.04	0.92	3.25	0.94	2.88	2.63	1.02	1.20	1.39	1.91	1.70	1.70	0.44
μ_{EH}	0.19	1.66	0.65	1.79	0.10	1.46	0.06	1.27	0.58	0.09	0.11	0.19	1.05	0.71	0.71	0.89
μ	0.28	0.63	0.47	0.79	0.25	1.04	0.25	0.92	0.76	0.27	0.32	0.38	0.64	0.54	0.54	0.49
SET 87	13	14	35	36	43	44	47	48	1	2	49	50	5	6	Mean	COV
μ	1.54	0.71	1.47	2.04	1.52	0.86	0.94	2.88	2.63	1.02	1.09	3.91	1.91	1.70	1.73	0.52
μ_{EH}	0.76	0.03	0.65	1.79	0.62	0.09	0.06	1.27	0.58	0.09	0.06	1.23	1.05	0.71	0.64	0.85
μ	0.50	0.18	0.47	0.79	0.48	0.23	0.25	0.92	0.76	0.27	0.29	1.18	0.64	0.54	0.54	0.55

Table 13. Six storeys irregular frame global response for moderate input intensity (a_g=3.99 m/sec^2)

SET 8	31	32	51	52	35	36	23	24	57	58	17	18	5	6	Mean	COV
μ	0.96	2.07	1.18	2.82	1.77	2.03	1.11	1.82	1.22	1.29	2.06	2.39	2.01	1.55	1.74	0.31
μ_{EH}	0.33	1.51	0.22	1.41	0.83	1.78	0.44	0.31	0.29	0.28	1.80	1.76	1.26	0.89	0.94	0.68
$I_{P\&A}$	0.36	0.91	0.42	1.14	0.70	0.93	0.43	0.64	0.44	0.46	0.95	1.05	0.85	0.64	0.71	0.37
SET 60	31	32	51	52	35	36	13	14	27	28	49	50	9	10	Mean	COV
μ	0.96	2.07	1.18	2.82	1.77	2.03	1.47	0.75	4.21	1.68	0.95	4.47	0.57	0.85	1.84	0.67
μ_{EH}	0.33	1.51	0.22	1.41	0.83	1.78	1.39	0.12	1.49	0.70	0.08	1.32	0.03	0.07	0.81	0.82
$I_{P\&A}$	0.36	0.91	0.42	1.14	0.70	0.93	0.69	0.26	1.61	0.66	0.32	1.67	0.19	0.29	0.73	0.66
SET 24	31	32	51	52	47	48	13	14	57	58	17	18	5	6	Mean	COV
μ	0.96	2.07	1.18	2.82	1.01	2.29	1.47	0.75	1.22	1.29	2.06	2.39	2.01	1.55	1.65	0.38
μ_{EH}	0.33	1.51	0.22	1.41	0.09	1.17	1.39	0.12	0.29	0.28	1.80	1.76	1.26	0.89	0.89	0.73
$I_{P\&A}$	0.36	0.91	0.42	1.14	0.34	0.93	0.69	0.26	0.44	0.46	0.95	1.05	0.85	0.64	0.68	0.43
SET 14	31	32	35	36	51	52	47	48	1	2	57	58	5	6	Mean	COV
μ	0.96	2.07	1.77	2.03	1.18	2.82	1.01	2.29	2.89	1.06	1.22	1.29	2.01	1.55	1.73	0.38
μ_{EH}	0.33	1.51	0.83	1.78	0.22	1.41	0.09	1.17	0.74	0.14	0.29	0.28	1.26	0.89	0.78	0.73
μ	0.36	0.91	0.70	0.93	0.42	1.14	0.34	0.93	1.06	0.37	0.44	0.46	0.85	0.64	0.68	0.41
SET 87	13	14	35	36	43	44	47	48	1	2	49	50	5	6	Mean	COV
μ	1.47	0.75	1.77	2.03	1.65	0.71	1.01	2.29	2.89	1.06	0.95	4.47	2.01	1.55	1.76	0.57
μ_{EH}	1.39	0.12	0.83	1.78	0.54	0.04	0.09	1.17	0.74	0.14	0.08	1.32	1.26	0.89	0.74	0.79
μ	0.69	0.26	0.70	0.93	0.62	0.24	0.34	0.93	1.06	0.37	0.32	1.67	0.85	0.64	0.69	0.57

Table 14. Four storeys regular frame global response for moderate input intensity (a_g=3.99 m/sec^2)

SET 8	31	32	51	52	17	18	5	6	57	58	35	36	23	24	Mean	COV
μ	0.75	1.30	1.43	2.62	1.82	2.14	1.66	2.10	1.55	1.58	2.24	1.64	0.98	1.39	1.66	0.30
μ_{EH}	0.17	0.42	0.38	0.68	0.73	1.70	1.03	0.99	0.51	0.35	0.97	1.11	0.18	0.36	0.68	0.63
$I_{P\&A}$	0.21	0.39	0.41	0.75	0.56	0.79	0.57	0.67	0.46	0.45	0.70	0.58	0.27	0.40	0.52	0.33
SET 95	43	44	51	52	17	18	1	2	27	28	13	14	53	54	Mean	COV
μ	0.94	0.87	1.43	2.62	1.82	2.14	3.17	1.24	3.00	1.59	2.01	1.21	0.64	0.99	1.69	0.47
μ_{EH}	0.14	0.15	0.38	0.68	0.73	1.70	0.67	0.17	0.78	0.74	2.05	0.80	0.02	0.56	0.68	0.84
$I_{P\&A}$	0.25	0.24	0.41	0.75	0.56	0.79	0.89	0.34	0.86	0.51	0.81	0.42	0.16	0.34	0.52	0.48
SET 24	31	32	51	52	17	18	5	6	57	58	13	14	47	48	Mean	COV
μ	0.75	1.30	1.43	2.62	1.82	2.14	1.66	2.10	1.55	1.58	2.01	1.21	0.93	1.99	1.65	0.31
μ_{EH}	0.17	0.42	0.38	0.68	0.73	1.70	1.03	0.99	0.51	0.35	2.05	0.80	0.19	0.50	0.75	0.73
$I_{P\&A}$	0.21	0.39	0.41	0.75	0.56	0.79	0.57	0.67	0.46	0.45	0.81	0.42	0.26	0.57	0.52	0.36
SET 14	31	32	35	36	51	52	47	48	1	2	57	58	5	6	Mean	COV
μ	0.75	1.30	2.24	1.64	1.43	2.62	0.93	1.99	3.17	1.24	1.55	1.58	1.66	2.10	1.73	0.38
μ_{EH}	0.17	0.42	0.97	1.11	0.38	0.68	0.19	0.50	0.67	0.17	0.51	0.35	1.03	0.99	0.58	0.57
μ	0.21	0.39	0.70	0.58	0.41	0.75	0.26	0.57	0.89	0.34	0.46	0.45	0.57	0.67	0.52	0.38
SET 87	13	14	35	36	43	44	47	48	1	2	49	50	5	6	Mean	COV
μ	2.01	1.21	2.24	1.64	0.94	0.87	0.93	1.99	3.17	1.24	1.04	3.60	1.66	2.10	1.76	0.48
μ_{EH}	2.05	0.80	0.97	1.11	0.14	0.15	0.19	0.50	0.67	0.17	0.09	0.77	1.03	0.99	0.69	0.79
μ	0.81	0.42	0.70	0.58	0.25	0.24	0.26	0.57	0.89	0.34	0.27	1.01	0.57	0.67	0.54	0.47

CONCLUSIONS

When the seismic response is evaluated by Nonlinear Response History Analysis, the demand is often assessed as the average values of response to samples of seismic excitation, often modelling the input by means of natural accelerograms. The efficiency of this procedure is conditioned by the choice of set of accelerograms in which each sample produce on the structure effects that are comparable with those induced by the target elastic response spectrum assumed for characterization of the seismic input. In this context, the performed numerical analyses showed that the ground motion intensity measures that have the larger correlation with the structural response are the Peak Ground Velocity PGV, the Housner index, and a new definition of the Effective Peak Ground Acceleration $EPA^*(T_i,T_I^d)$, where the latter is referred to i^{-th} the period of vibration of the structure in the elastic phase T_i and the damaged one T_i^d. The period of damaged structure can be assumed as non integer multiple of T_i depending on the estimated behaviour factor associated at the correspondent vibration mode. Global structural response parameters of plane frame are correlated mainly on EPA^* of first vibration mode, while local response parameters can be more correlated with ordinate of elastic response spectrum of higher modes.

In order to reduce the scattering of the results of each sample of a set of spectrum-compatible accelerograms, an accelerogram choice criterion based on the mean value and the minimum value of Coefficient of Variation of EPA* is proposed.

Non-linear Response History Analysis for three multi-storey frames was performed assuming as input sets of natural accelerograms chosen according different criteria proposed in literature and the proposed one. The numerical results showed that, when high input intensity level is considered and accelerograms in the set have scattered damage potential, the assessment of the response is obtained by averaging results that are obtained for seismic demand largely beyond the capacity of the structure, having values strongly influenced on the modelling of the element behaviour assumed beyond the collapse condition. Thus, results that lack in accuracy are obtained. Conversely, when small to moderate input intensity is considered, the assessment of the response is obtained by averaging results that in many cases describes the elastic behaviour of the structure only, i.e. are not able to reproduce the main characteristic of the non linear response that largely depends on the distribution of the element strength in the structure.

The proposed criterion of selection of the accelerograms, based on the minimum value of the Coefficient of Variation of the modified expression of the Effective Peak Acceleration is efficient in solving both these two drawbacks.

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