A new energetic based ground motion selection and modification algorithm equation

A new energetic based ground motion selection and modification algorithm.

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ABSTRACT. This paper presents a new ground motion modification and selection procedure to be used for performing the response history analysis of structures. The proposed selection and scaling procedure is based on an energetic comparison in a frequency band. The Conditional Mean Spectrum is used as target spectrum while only the records providing a relevant contribution to the hazard at the site are considered.
The set of ground motion with the same hysteretic energy demand is obtained matching the acceleration of the target spectrum at the period of interest T_{ref} and selecting only the scaled spectra having a similar Housner intensity in the period range $0.2T_{ref} - 2T_{ref}$.
A set of records which are spectrum compatible, having a similar hysteretic energy demand are obtained.
This last aspect can be reflected in terms of equal damage level expected on the structure, since the damage parameters coming from the response history analyses present a very low dispersion.
As a result, the new energetic approach allows selecting a set of ground motion according to the spectrum-compatibility criterion, to the frequency content representativeness and to the consistency of the expected structural damage for the given hazard scenario.

1. INTRODUCTION

Prediction of the response of structural and geotechnical systems to an earthquake excitation is the goal of performance-based earthquake engineering. Nowadays, due to the developing of a large quantity of finite element software and with the increase of efficiency of computers, the scientific efforts are aiming to dynamic Non-linear Response History Analyses (NRHA).
Furthermore, the availability of large ground motion databases allows to perform time history analysis using real ground motion records.
Artificial or synthetic accelerograms are used in the dynamic analyses, but they have restrictions due to impossibility to describe realistica4lly the earthquake characteristics. For this purpose, real ground motions records do not have distortion in the waveform characteristics, especially in terms of frequency and energy content.
Seismic hazard at the reference site and the structure behavior (mark out by its first period) have to be considered in order to obtain the target spectrum. It represents the base of the ground motion selection procedure and takes into account the probabilistic hazard of the site for a given exceedance probability.
The selection of real ground motion records is carried out in order to have an adequate mean spectrum-compatibility, through modification of each time history using a Scale Factor (SF).
A large variety of Ground Motion Selection and Modification (GMSM) procedure are proposed according to their purpose. The *Seismic Performance Assessment of Buildings* (ATC-58-1, 2012) defines three selection methodologies:

1. *intensity-based assessment;*
2. *scenario-based assessment;*
3. *time-based assessment*

Different intensity-based GMSM methods are based on the common statement consisting in modifying the real records to have the same intensity measure (IM) obtained from Probabilistic Seismic Hazard Analysis (PSHA). The scaling of ground motions are performed to match a target design response spectrum (Katsanos et al. 2010). The most used IM parameter is the spectral acceleration corresponding to the fundamental period (reference period) of the structure with a damping ratio of 5%.
In these cases, the selection of real accelerograms is performed on the basis of mean compatibility between their response spectra and a target spectrum (spectral matching). For *intensity-based methods*, spectral matching is commonly used to select earth-

quake record. Several authors proposed some formulation to take into account the dispersion quantity between the generic elastic response spectrum and the target one. Ambraseys et al. (2004) proposed to verify spectral compatibility of a given record according to the parameter reported in Equation (1):

$$D_{ms} = \frac{1}{N}\sqrt{\sum_{i=1}^{N}\left(\frac{Sa_0(T_i)}{PGA_0} - \frac{Sa_S(T_i)}{PGA_S}\right)^2} \qquad (1)$$

where N is the number of periods within the reference interval, $Sa_0(T_i)$ is the spectral acceleration of the record at period T_i, $Sa_s(T_i)$ is the target spectral acceleration at the same period value, and PGA_0 and PGA_s are the peak ground acceleration of the record and the period equal to zero and the reference period, respectively. Iervolino et al. (2009) proposed an expression for the average spectrum deviation of the record with respect to the target one in the range period of interest (Equation (2)).

$$D_i = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{Sa_j(T_i) - Sa_S(T_i)}{Sa_S(T_i)}\right)^2} \qquad (2)$$

In this case, the value of PGA is not considered as normalization factor.
The scenario-based assessment is carried out according to the earthquake magnitude (M), source-to-site distance (R), faulting system and soil class of site. Shome et al. selected sets of real accelerograms based on the basis of four different magnitude–distance pairs, permitting a limited variation in the target values. Recent studies have shown the inefficacy of selection procedure based on M-R for the structural dynamic response. Baker & Cornell (2006) confirmed that the source-to-site distance R is statistically insignificant to the structural response, while the earthquake magnitude gives significant contribution.
In order to perform a soil response analyses or liquefaction analyses, the characteristics of the soil profile should be considered into the selection process. Thus, site classification in terms of shear waves velocity at the uppermost 30 m ($V_{S,30}$) becomes an essential parameter. In this case the earthquake scenario will be defined by means of the parameters M-R-$V_{S,30}$.

The description of the new method will be discussed in detail in paragraph 2, while in paragraph 3 the advantages associated with the method will be presented.
Finally, a case study will be presented in paragraph 4. The structural performance of regular building will be investigated. The ground motion selection and modification procedure will be carried out through using the associated tool of OPENSIGNAL 4.1 software (Cimellaro & Marasco, 2015).

2. DESCRIPTION OF THE METHOD

A new ground motion selection and modification procedure is proposed to minimize the dispersion value of the Engineering Demand Parameters (EDPs) obtained by the dynamic analyses of the structure. A set of ground motions that determines a low variability of the structural response allows defining fragility curves for structural components with good accuracy. In a context of seismic performance assessment of a structural system, increasing the accuracy lead to more careful estimation of consequence functions and resilience indexes.
Figure 1 shows the generic flowchart that describes the selection procedure of the ground motion set.

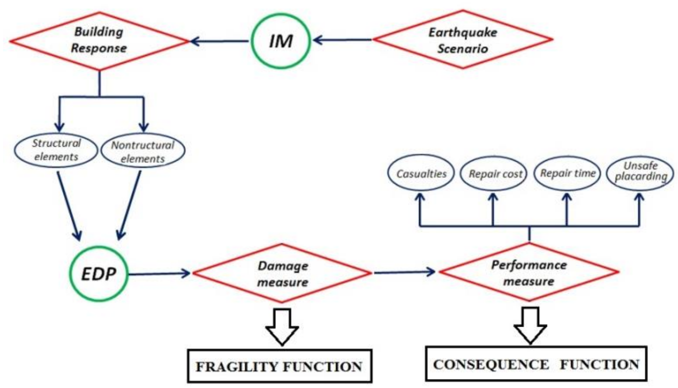

Figure 1. Seismic performance evaluation of a building.

2.1 *Target spectrum*

The first assumption of the method refers to the target spectrum used in the selection procedure. The Uniform Hazard Specrtum (UHS) is widely used as target spectrum in the dynamic analyses of buildings. It comes from PSHA (Allin & Cornell, 1968) and defines the locus of spectral acceleration value at each period having given exceedance probability. Ground motions with different magnitudes and epicentral distances contribute to the total hazard. It was observed that the high-frequency portion of the UHS is dominated by small nearby earthquakes, while the low-frequency portion is dominated by larger, more distant earthquakes. The UHS is not very representative as target spectrum for any individual seismic excitation because no single earthquake will produce a response in a wide range of frequency content.
This limitation has led to focus on the Conditional Mean Spectrum (CMS-ε) which is obtained conditioning on a spectral acceleration at only one period (reference period of the structure), according to commonly used de-aggregation parameters M, R and ε. The last parameter is a measure of the difference between the logarithmic spectral acceleration of a record and the mean or median logarithmic spectral demand predicted with a given attenuation model for the considered site.

Baker & Cornell (2006) investigated the dynamic response of a multi-degree of freedom system according to ground motions of a specified intensity (as measured of spectral acceleration at first period of the structure) and matching UHS and CMS-ε. It was observed that records selected based on CMS-ε produce smaller dispersions in structural dynamic response than records obtained with the UHS.

2.2 *Modification procedure*

Usually, the IM parameter used in the ground motion selection approaches is the spectral acceleration at the period of interest ($S_a(T_{ref})$). It is a good measure of the maximum seismic action absorbed elastically by the structure. In general, for MDOF systems, the period T_{ref} can be assumed equal to the first vibrational mode (T_1), since the dynamic response of the structure is governed by the first mode. When the mass and the stiffness of the structure are not uniformly distributed in plan and elevation, its dynamic response is evaluated as linear combination of the modes. It is suggested to consider every mode such that the sum of the modal participation factors in the two horizontal directions is greater than *85%-90%*. In these cases, the reference period can be obtained as a weight-average of the periods associated with the N modes of interest using the modal participation factor as weight factor (Equation (3)).

$$T_{ref,h} = \frac{\sum_{i=1}^{N} T_{i,h} \cdot |g_{i,h}|}{\sum_{i=1}^{N} |g_{i,h}|} \tag{3}$$

where T_i and g_i identify the i^{th} mode period and modal participation factor, respectively; while h index is associated with the horizontal component of the motion.
The number of real ground motions available in the online databases is not adequate to identify a large number of records with the same spectral acceleration at the reference period. Thus, modification of the records is an inevitable step to have a numerous set of compatible ground motions.
Most of the modification procedure are based on the scaling the spectral acceleration at reference period of the record ($S_{a,i}(T_{ref})$) to the target spectral acceleration ($S_{a,TS}(T_{ref})$) (Equation (4)).This imposition lead to consider records causing the same maximum seismic action on the structure in the elastic field.

$$SF_{I,i} = \frac{S_{a,TS}(T_{ref})}{S_{a,i}(T_{ref})} \tag{4}$$

The new proposed method modifies each record in two steps: one according to previously mentioned, and the other one based on the Housner intensity value at period range of interest. For every record, the Housner intensity is calculated in the range $\Delta T = 0.2 \cdot T_{ref} - 2 \cdot T_{ref}$ ($I_{H,i}(\Delta T)$) that corresponds to the period interval in which the mean spectrum-compatibility has to be respected. The target Housner intensity ($I_{H,TS}(\Delta T)$) is evaluated from the Pseudo Velocity Spectrum (PVS), obtained by dividing the acceleration target response spectrum at each j^{th} period by the associated angular frequency $\omega_j = 2 \cdot \pi / T_j$. Equation (5) illustrates the Housner intensity based scale factor of i^{th} record.

$$SF_{II,i} = \frac{I_{H,TS}(\Delta T)}{I_{H,i}(\Delta T)} \tag{5}$$

2.3 *Selection procedure*

The new selection procedure is based on the energy content of the ground motion in the different frequency bands. As well-known, the energy of a periodic signal is directly proportional to its square amplitude. According to Fourier, an earthquake can be decomposed in infinite harmonic periodic functions having given amplitude (A_i) and frequency (ω_i). Fourier transform gives information about the amplitude contribution for each frequency of the ground motion. Thus, from the Fourier transform it is possible to evaluate the trend of the square amplitude (A_i^2) in the frequency domain. This parameter is used as energy proportional parameter. In order to simplify the results, the frequency domain can be sampled in different bands (Δf) of 0.5 Hz. For each Δf, the cumulative energy proportional coefficient can be evaluated as sum of each single contribution in the given band. This method leads to characterize the energy band content of the ground motion.
The same procedure cannot be used to define the energy content of the target which is the acceleration response spectrum.
The target energy content is calculated with a simple approach based on the amplification function (|A|). After sampling the period domain of the target spectrum for each discrete period, the amplification function is evaluated as ratio between the spectral acceleration at a given period and the spectral acceleration at T=0 (Peak Ground Acceleration (PGA)). Equation (6) shows the amplification function for the i^{th} period value.

$$|A_i| = \frac{S_{a,TS}(T_i)}{S_{a,TS}(T=0)} = \frac{S_{a,TS}(T_i)}{PGA_{,TS}} \tag{6}$$

According to the definition of amplification function and setting a damping ratio ξ equal to 5%, the predominant frequency of the target ($\omega_{f,i}$) can be calculated from the Equation (7).

$$|A_i| = \frac{1}{\sqrt{\left(1-\left(\frac{\omega_{f,i}}{\omega}\right)^2\right)^2 + \left(2\cdot\xi\cdot\frac{\omega_{f,i}}{\omega}\right)^2}} \quad (7)$$

Appling the same procedure to every period range, a distribution of $(|A_i|)^2$- $\omega_{f,i}$ is defined. Dividing the frequency domain in bands of 0.5 Hz and summing every contribution inside them, the target energy band in percentage is obtained. Figure 2 summarizes the procedure above.

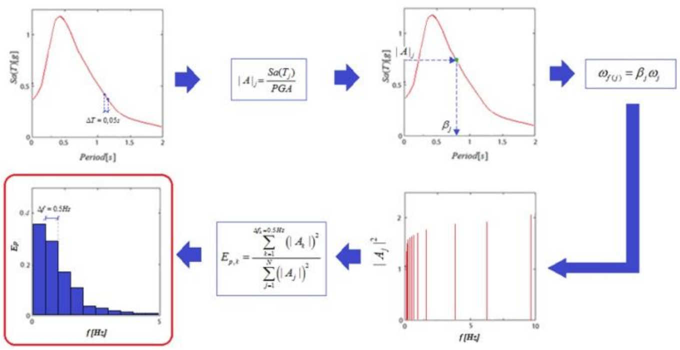

Figure 2. Scheme of the procedure used to obtain the energy content in the discretized frequency domain.

The selection procedure is described in the following step-by-step procedure:

1) Set the maximum and minimum value of SF_I and select all the records within the interval $SF_{I(min)}$-$SF_{I(max)}$.
2) Set the maximum absolute percentage dispersion of PGA (σ_{PGA}).
3) Set the maximum and minimum values of moment magnitude and epicentral distance according to the de-aggregation at the site.
4) Select only the records satisfying the condition reported in Equation (8).

$$(1-\sigma_{SF}) \le \frac{SF_{I,i}}{SF_{II,i}} \le (1+\sigma_{SF}) \quad (8)$$

where σ_{SF} represents the dispersion coefficient associated with the scale factors. It is suggested to choose a dispersion value lesser than 15 %.

5) Among the records coming from step 1) and 2), a set of seven records (in both horizontal directions for structural analyses and in a given horizontal direction for performing soil response analyses) is selected by comparing energy content of each record with the target one.

This step is the real innovation of the method since the spectrum-compatibility is achieved with reference to the energy content of the ground motions.

For generic compatible record, the energy trend coefficient (C_E) reported in Equation (9) is evaluated.

$$C_E = \frac{1}{\left[|E_{p,j(i)} - E_{p,j(TS)}| \cdot \lambda_i\right]} \quad (9)$$

where $E_{p,j(i)}$ and $E_{p,j(TS)}$ represent the energy percentage content for j^{th} frequency band of the i^{th} record and for the target, respectively. The coefficient λ_i indicates the cumulative shape dispersion of the energy content of the i^{th} record with respect to the target one (Equation (10)).

$$\lambda_i = \sum_{j=1}^{20} |E_{p,j(i)} - E_{p,j(TS)}| \quad (10)$$

Since the significant frequency content of an earthquake does not exceed the value of 10 Hz and the frequency domain has been sampled at 0.5Hz, the total percentage energy contributions are 20 in this case. All the records will be sorted descending using the C_E values for each of the 20 frequency bands. According to the percentage contributions of energy band content, a number n_j of records will be selected for each band having the greater values of C_E coefficient. In this specific case, the procedure starts from *Δf: 0-0.5 Hz* and will be stopped when the progressive number $\sum_{j=1} n_j$ reach the value of 7.

3. ADVANTAGES OF THE PROCEDURE

3.1 *Consistency with the hazard*

The selection procedure has been applied using the de-aggregation information at a given site. This allows selecting only the records having M-R that gives substantial contribution to the hazard.

3.2 *Consistency with target PGA*

The selection procedure based only on the spectral acceleration at the reference period can lead to have PGA not close to the value coming from the hazard analysis. This has implications in terms of inadequate spectrum-compatibility in the range of low periods. In addition, wide variability of PGA for a set of records can produce big scattering of the maximum dynamic responses of a structure. This last aspect is in contrast with the goal to be achieved in the analyses. Thus, setting a maximum absolute dispersion of PGA with respect to the target one tends to limit the variation of the dynamic response of a system. It is suggested to use σ_{PGA} lesser than 20 %.

3.3 *Equal elastic seismic action*

The first proposed modification approach is usually used in other GMSM procedure. It has the advantage to scale each record causing similar maximum elastic action on the structural system described by its reference period T_{ref}.

However, the scaling procedure must not to be such that causes a distortion in frequency and energy content of signal. For this purpose it is suggested to set restrained values of $SF_{I(min)}$ and $SF_{I(max)}$.

3.4 *Hysteretic energy demand control*

The scaled records will be selected if the ratio between the scale factors based on the reference spectral acceleration and on the Housner intensity. It has not

to exceed the value $1 \pm \sigma_{SF}$, where the dispersion parameter is chosen in order to be lesser than 15 %.
This imposition is equivalent to consider records having approximately the same value of Housner intensity as well as to cause elastic seismic action on structure. Since the Housner intensity is a measure of hysteretic demand, each modified record causes in the structure a roughly equal hysteretic energy dissipation (E_H).
Further advantage of this modification procedure is reflected in the mean spectrum-compatibility. In fact, having an approximately equal Housner intensity leads to control the mean values of the PSV and then the acceleration response spectrum for each record.

3.5 *Input energy control*

The records are chosen to have energy compatibility with the target distribution in the frequency domain.
In addition, the maximum amplitudes of the records are similar, since the PGA has low dispersion compared to the hazard value. Thus, the new proposed selection procedure provides a set of motions with approximatively equal energy.
The Arias intensity (I_A) is one of the most diffused integral parameter that describes the total amount of energy of a ground motion. According to the previous observations, it is possible to claim that the energy-based selection procedure is capable to control the input energy on the structure, providing a set of motions with very low Arias intensity variability. A selection procedure based on the energy content in the frequency domain ensures a good mean spectrum compatibility with the target spectrum.

3.6 *AV ratio control*

According to Tso, Zhu & Heidebrecht (1991), the energy and frequency content of a ground motion are related to the ratio between its peak ground acceleration and velocity (AV).
Analyses of 45 records led to identify three groups of AV ratio values (low, intermediate and high). Records of a given group showed a similar trend in terms of energetic content in the frequency domain.
Since the records selected with the new approach have a modest variability of energetic contributions in the frequency domain, each of them will have small dispersion of AV ratio. In other words, the proposed selection procedure is capable to control the peak velocity of ground motions (PGV) if the peak acceleration is close to the target one.

3.7 *Damage control*

The damage of a structural system induced by a seismic excitation is directly proportional to the number (n) and amplitude (m) of plastic load-unload cycles to which the structure is subjected. Manfredi and Cosenza (1997) proposed a damage index (I_D) that describes the damage level of a structure by means of Arias intensity, PGA and AV ratio (Equation (11)).

$$I_D = \frac{2 \cdot g}{\pi} \cdot \frac{I_A}{PGA^2} AV \qquad (11)$$

According to the Manfredi and Cosenza formulation, the ground motion hysteretic energy demand (E_H) is reported in Equation (12).

$$E_{h,d} = F_y \cdot \left(\Delta u_{\max} - \Delta u_y\right) \cdot \left[1 + m \cdot (n-1)\right] \qquad (12)$$

where m and n coefficient have been previously defined and they are directly proportional to I_D. The yielding action and displacement have been expressed by F_y and Δu_y, respectively. These two parameters are intrinsic of the structure, while Δu_{max} represents the maximum dynamic response of the structure in terms of displacements.
According to Equation (12) and using a set of ground motion coming from the proposed procedure, the control of the hysteretic energy (E_H), PGA, AV ratio and Arias intensity (I_A), lead to obtain a controlled dynamic response of the structure (Δu_{max}). Considering a multi-story building, its dynamic response can be alternatively expressed as sum of drift contribution at each story ($\sum_i \Delta u_{\max,i}$). Thus, it can claim that the new GMSM procedure lead to control the maximum story drift caused on the structure, obtaining a very low dispersion among the seven selected records. Naturally, the efficiency of the method depends on the dispersion coefficients values used in the procedure.

4. CASE STUDY

As illustrative example, a set of seven records have been selected with the methodology above discussed. The selection procedure has been carried out using the software OPENSIGNAL 4.1 (Figure 3).

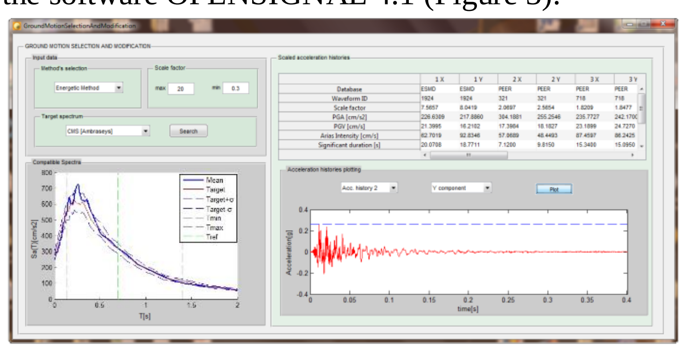

Figure 3. "GroundMotionSelectionAndModification" component of OPENSIGNAL 4.1 software.

The selected records have been used as inputs for non-linear dynamic analysis of a structure, to examine the differences in the structural responses. The structure is a five-story reinforced concrete frame building with regular mass and stiffness distribution. The building is located in the Southern Italian site of Soveria Mannelli (Lat: 16.3667, Long: 39.0833).

A F.E.M. model of the building in SAP2000 have been used considering 30x50 cm, 50x30 and 40x30 cm for external and internal beams, respectively; while a section 45x45 cm has been adopted for columns (Figure 4).

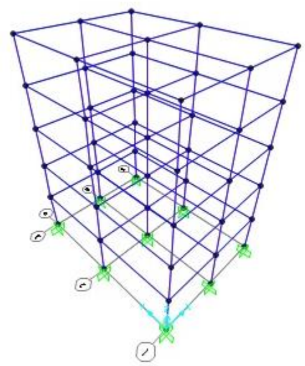

Figure 4. 3D F.E.M. model of the five-story building.

The nonlinearity of the structural elements have been considered using a concentrated plasticity model. For this purpose, *Caltrans Flexural Hinge* (type *Moment M2-M3,* displacement control) have been used for beam elements, while *Caltrans Interacting* (type *P-M2-M3* with M-χ cylindrical domain) have been modeled for columns.

The building model has elastic first mode period of 0.7 s and the associated spectral target acceleration is used as the IM parameter.

The hazard parameters for the reference site have been considered for a probability of exceedance of 10% in 50 years. For the reference site, the associated CMS has been defined using OPENSIGNAL 4.1 software and it has been used as target spectrum. The set of seven groups of records are selected and reported in Table 1 and Table 2 with the associated characteristics.

Table 1. Waveform parameters of the WE record components.

Database	ESMD	PEER	PEER	PEER	PEER	PEER	PEER
Number	1	2	3	4	5	6	7
Scale factor	4.07	1.70	2.27	1.00	3.16	1.74	4.25
PGA [m/s2]	3.13	2.20	3.06	2.63	3.12	2.69	2.97
PGV [m/s]	0.21	0.22	0.22	0.14	0.25	0.19	0.20
I_A [m/s]	0.66	0.76	0.49	0.69	0.52	0.58	0.80
Duration [s]	21.10	15.34	4.22	9.61	8.80	8.46	12.76
AV [gs-1]	1.51	1.04	1.45	1.90	1.26	1.46	1.53
I_D	0.06	0.10	0.05	0.12	0.04	0.07	0.09
Mw	5.90	6.22	5.61	5.77	5.90	5.74	6.61
R_{epi} [km]	22.00	24.79	19.95	12.38	33.94	7.95	29.41

Table 2. Waveform parameters of the NS record components.

Database	ESMD	PEER	PEER	PEER	PEER	PEER	PEER
Number	1	2	3	4	5	6	7
Scale factor	4.73	1.72	1.92	0.96	1.50	1.00	2.69
PGA [cm/s2]	3.21	2.26	3.20	3.03	2.62	2.74	2.86
PGV [cm/s]	0.15	0.23	0.15	0.16	0.16	0.20	0.17
I_A [cm/s]	0.84	0.75	0.49	0.82	0.29	0.36	43.16
Duration [s]	18.53	15.10	5.38	6.11	4.47	5.43	12.36
AV [gs-1]	2.22	1.00	2.22	1.99	1.67	1.37	1.69
I_D	0.11	0.09	0.06	0.11	0.04	0.04	0.05
Mw	5.90	6.22	5.61	5.77	5.90	5.74	6.61
R_{epi} [km]	22.00	24.79	19.95	12.38	33.94	7.95	29.41

The earthquake adopted are listed below:

- 1: Umbria-Marche-Italy;
- 2: San Fernando-California;
- 3: Dursunbey-Turkey;
- 4: Coalinga-California;
- 5: Whittier Narrows-California;
- 6: Sierra Madre- California
- 7: Chi Chi-Taiwan.

Figure 5a illustrates the comparison between the mean spectrum obtained from the seven groups of records and the mean spectrum, while Figure 5b shows the comparison between the target spectrum (CMS-ε) and the mean spectrum obtained from the selected set.

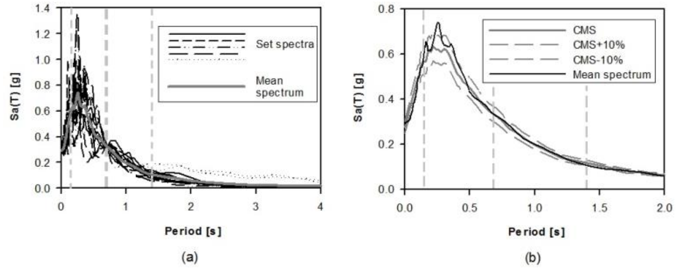

Figure 5. Elastic response spectra of the selected set and associated mean spectrum (a). Comparison between target spectrum and mean spectrum (b).

It is possible to appreciate the excellent spectrum-compatibility, especially for the periods close to the reference one. The mean spectrum does not exceed the 10 % of the target spectrum in almost every periods within the range of interest. According to the considerations made in the previous paragraph, it is possible to appreciate the low variability of the waveform parameters in the Table 3.

Table 3. Normal mean and standard deviation of waveform parameters of the selected set of ground motion.

Parameter	θ_N	β_N / θ_N
PGA [cm/s2]	283.58	0.12
PGV [cm/s]	18.85	0.19
I_A [cm/s]	60.56	0.30
Duration [s]	10.55	0.52
AV [gs-1]	1.59	0.24
I_D [-]	0.07	0.37
Mw [-]	5.96	0.06
R_{epi} [km]	21.49	0.41

In table 3 θ_N represents the mean value, while the dispersion parameter is β_N, according to a normal distribution. The maximum observed inter-story drift ratio, maximum floor acceleration and velocity have been used as EDPs. Figure 6 shows the percentage inter-story drifts obtained for the seven groups of records.

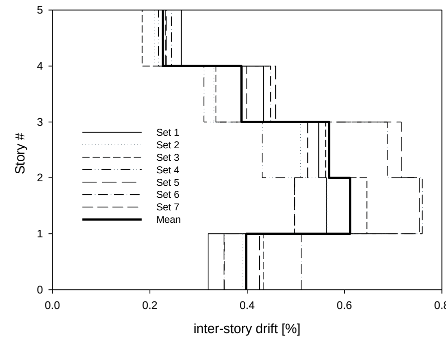

Figure 6. Inter-story drift of the seven groups of selected records compared with the mean values.

Table 4, Table 5 and Table 6 summarize the obtained structural parameters with the relative mean (θ) and standard deviation (β) according to lognormal distribution.

Table 4. Mean and dispersion values of the inter-story drifts.

	Inter-story drift [%]				
Story	1	2	3	4	5
θ	0.394	0.603	0.561	0.384	0.225
β	0.025	0.032	0.0309	0.026	0.014
β/θ	0.064	0.053	0.055	0.068	0.060

Table 5. Mean and dispersion values of the floor velocities.

	Floor velocity [m/s]				
Story	1	2	3	4	5
θ	0.234	0.275	0.336	0.413	0.492
β	0.0424	0.028	0.018	0.011	0.0075
β/θ	0.181	0.102	0.055	0.026	0.015

Table 6. Mean and dispersion values of the floor accelerations.

	Floor aceleration [m/s^2]				
Story	1	2	3	4	5
θ	3.740	4.327	3.763	4.152	6.514
β	0.02	0.0313	0.012	0.0047	0.0298
β/θ	0.005	0.007	0.003	0.001	0.005

The dispersion values of the structural response parameters normalized with respect to their mean coefficient assume always small values. Thus, the set of 7 groups of ground motions are such as to provide very low variability in terms of dynamic response of the building.

5. CONCLUDING REMARKS

Nowadays, the availability of large ground motion databases allows performing time history analysis using real ground motion records. Since the main goal of the response history analyses is to predict the dynamic behavior of the structures, the main concern is the selection of a set of ground motions that determines a low variability in the structural response.
The new proposed GMSM procedure based on the energy content of the records leads to control the main parameters that affect the dynamic response of a structure. Furthermore, the selected records are consistent with the seismic hazard at the site, in terms of M-R parameters and spectral acceleration at the reference period.
The advantage of the proposed modification and selection procedure is that the set of ground motions generates the same elastic response and they approximately produce the same plastic dissipation on the structure.
Thus, this procedure is capable to minimize the dispersion of the structural dynamic response parameters (EDPs) with respect to the mean value.
The low variability of the EDPs allows increasing the accuracy on the estimation of casualties, repair time, repair costs, etc.. Therefore, the new GMSM procedure can be used to define the earthquake scenario for resilience analyses of a single building or for a group of buildings.

6. ACKNOWLEDGEMENTS

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