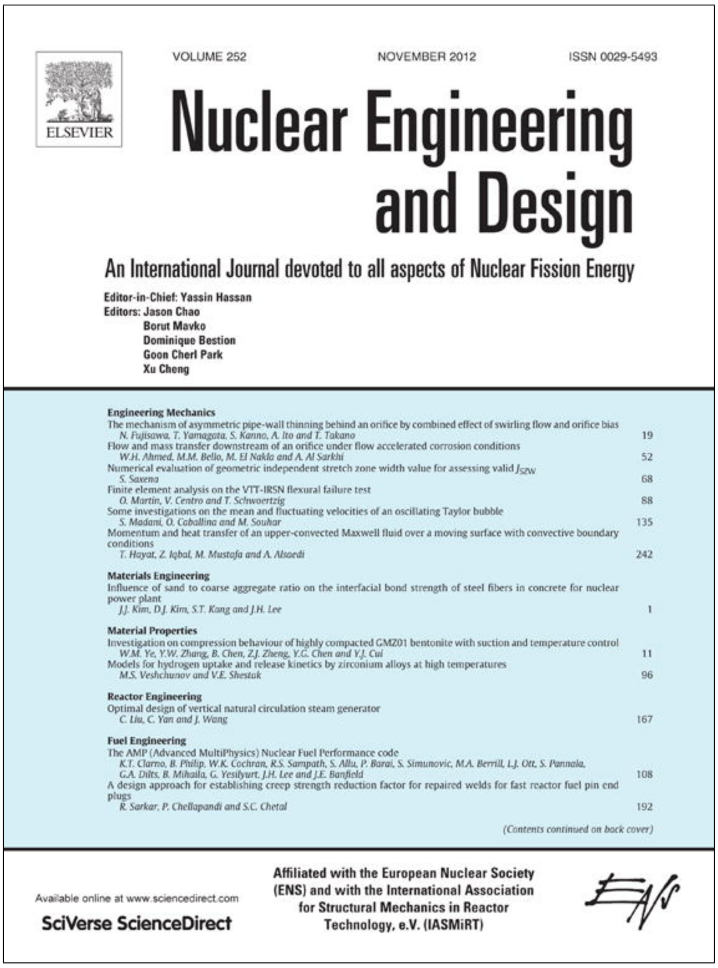

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E-CMS: A new design spectrum for nuclear structures in high levels of seismic hazard

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HIGHLIGHTS

- ► A new approach for selection of the appropriate ground motion records.
- ► A new design spectrum for NRC 1-165 standard.
- ► The ECMS spectrum has been proposed for nuclear structures design.

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ABSTRACT

The target spectrum which has been used most frequently for the seismic analysis of structures is the uniform hazard response spectrum (UHRS). The joint occurrence of the spectral values in different periods, in the development of UHRS, is a key assumption which remains questionable. The conditional mean spectrum (CMS) has been recently developed by Baker et al. as an alternative for UHRS. The CMS provides the expected response spectrum conditioned on the occurrence of the target spectral acceleration value in the period of interest which can be accounted as an improvement of the UHRS. In order to enhance the CMS, the correlation between the peak ground velocity (PGV) and the spectral acceleration values has been investigated in the current study, and finally, a newer form of target spectrum has been proposed. It is shown that the emerged new spectrum, named Eta-based conditional mean spectrum (E-CMS), is more efficient than the conventional CMS in order to enhance the UHRS. The nuclear industry design guidelines (i.e. Nuclear Regulatory Commission Guides 1.165 and 1.208) provide an alternative procedure based on UHRS for defining the design spectrum which has been compared with the proposed CMS and E-CMS. The results show that the alternative procedure might be somehow conservative for stiff structures such as nuclear facilities.

1. Introduction

One of the most important challenges in structural response assessment is the careful ground motion record (GMR) selection before performing dynamic analyses. All of researchers and guidelines emphasize that ground motion records should represent the properties of a given hazard level which can be quantified based on probabilistic seismic hazard analysis (PSHA) (McGuire, 1995). Most of the design codes use a suitable target spectrum to facilitate ground motion record selection approach and finally use those GMRs as input to dynamic analysis (ASCE7-5, 2005). The uniform hazard response spectrum (UHRS) is considered to be as a commonly used target in most of design codes and guidelines. However most of recent research results have shown that UHRS is not a good representative of a suitable target (McGuire, 1995). The UHRS is an elastic spectrum at a site with a given hazard level which the structure is supposed to be located. The spectral acceleration amplitudes in UHRS would be more that the median predicted spectrum in all periods within a single ground motion. This fact is more highlighted when the UHRS is compared with the spectral shape records in higher hazard levels. Fig. 1 shows the UHRS given exceedance of the spectral acceleration (*Sa*) values with 2475 years return period. By considering a structure with the first period of one second, only one (none scaled) rare record is found to have *Sa* value equal to UHRS in the target period. In other words the mentioned record in Fig. 1 has an Epsilon value in the target period approximately equal to 1.7 in which Epsilon (Baker and Cornell, 2006a) is defined as the number of standard deviations from the predicted value by an empirical ground motion model. As seen in Fig. 1, it is obvious that there is clear observed difference in other periods between the selected record and the UHRS. In other words this fact illustrates why the

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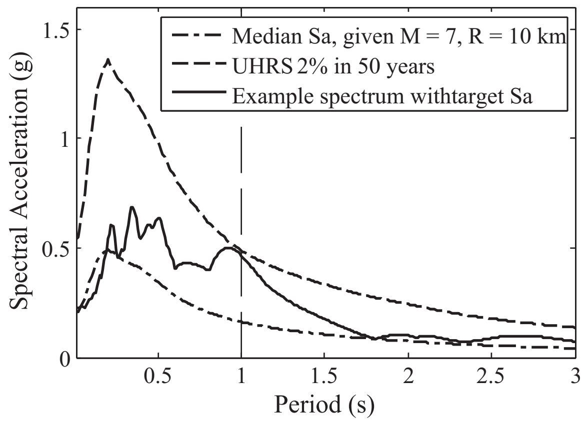

Fig. 1. Median predicted spectrum using BA-08 attenuation relationship (Boore and Atkinson, 2008), having $M = 7$ and $R = 10$ km. UHRS for 2% probability of exceedance in 50 years. The example record spectrum is the Parkfield-Fault Zone 16 recorded from Coalinga event.

uniform hazard spectrum is not a good representative of individual ground motion spectrum. As UHRS in lower period range is affected by strong ground motions and weak earthquakes have the most contribution in the UHRS values in lower frequencies, UHRS has not satisfied users to be a suitable target spectrum in ground motion record selection purposes and considered as a conservative target by researchers e.g. McGuire (1995). On the other hand nuclear industry design procedures provide an alternative method to obtain the design spectrum (NRC, 2007).

The conditional mean spectrum (CMS) has been introduced by Baker in recent years to decrease the UHRS disadvantages (Baker, 2011). The Epsilon as a spectral shape indicator is employed in CMS (Baker and Cornell, 2006a). The CMS is a method that accounts for magnitude, distance and Epsilon values likely to cause a given target ground motion intensity at a given site for a specified hazard level. The main assumption in CMS is that the only value which would be exactly equal to the target value (*Sa* in UHRS) is located at the target period. In fact CMS has a peak value at the target period and decays toward the median spectrum in other periods. The decreasing process is based on a correlation model between the spectral acceleration values for all periods. This correlation is not taken into account in the UHRS concept since UHRS is based on several independent PSHA analyses for each period with no joint occurrences of spectral values.

The spectral acceleration is the only intensity measure (*IM*) which is employed in the Epsilon spectral shape indicator. An alternative indicator, as a more reliable predictor of the non-linear response of structures, is recently proposed by Mousavi et al. (2011) which is named Eta. It has been shown that a simple linear combination of different *IM* Epsilons can result in a robust predictor of non-linear structural response. In addition to the spectral acceleration, the peak ground acceleration, the peak ground velocity and the peak ground displacement are also assumed as *IM*s in the prediction of the new spectral shape indicator. A new target conditional mean spectrum is presented here which uses the Eta advantages instead of the conventional Epsilon. The Eta-based conditional mean spectrum (E-CMS) provides the mean response spectrum conditioned on occurrence of a target spectral acceleration value in the period of interest by considering of a new correlation model that is based on the new spectral shape indicator.

The Nuclear Regulatory Commission (NRC) and ASCE/SEI Standard 43-05 suggest an approach for identification and characterization of the seismic sources and determination of the safe shutdown earthquake (SSE) (see NRC, 2007; ASCE, 2007). The SSE is the vibratory ground motion for which certain structures, systems and components (SSCs) are designed to remain functional. All SSCs are placed, for design purposes, into different seismic design categories according to their importance. The final aim is to develop the site-specific design ground motion record spectra which can be based on the mean site-specific UHRS modified by a design factor (DF). One of the disadvantages of NRC target is that the supposed spectrum is independent of the target period which is usually considered to be the first period of vibration while the CMS uses the period of structure (Baker, 2011) as the key input.

Replacing Eta indicator instead of the conventional Epsilon in the conditional computation leads to introduction of a new target response spectrum which shows more consistency with the nuclear guidelines target spectra. This issue is discussed in details in the current study.

2. Spectral shape, Epsilon and Eta

2.1. Spectral shape indicators

Recent studies have shown that for ground motion records with the same spectrum value in a given period, the spectral shape has an important influence on the response of higher modes of structures as well as on its non-linear behavior (Baker and Cornell, 2005). The Epsilon, as defined mathematically in Eq. (1), is a key indicator which can control the spectral shape. The Epsilon is the number of standard deviation by which a given intensity measure value differs from the mean predicted *IM* value for a given magnitude and distance. It is shown that the Epsilon indicator can be a robust predictor of the spectral shape (Baker and Cornell, 2006a). The Epsilon also has high correlation with structural collapse capacity values (Haselton et al., 2011) as discussed in Section 2.2. Therefore these summarized advantages are enough to identify Epsilon as an applicable indicator in structural analysis and design. The spectral acceleration value is the most important intensity measure against other ground motion intensity parameters. *Sa* has been widely employed in the common non-linear dynamic analysis procedure which is termed incremental dynamic analysis (IDA) (Vamvatsikos and Cornell, 2002). The discussed Epsilon uses *Sa* as *IM* which means that the conventional Epsilon is based on only one intensity measure. However Mousavi et al. (2011) have recently shown that a simple combination of *IM* Epsilons can result in more robust prediction of the spectral shape in comparison with the conventional Epsilon. A linear combination of the *Sa* Epsilon with the peak ground velocity (PGV) Epsilon is introduced as a new indicator of elastic spectral shape. This new indicator, named Eta, has shown more correlation with structural non-linear response. In fact it is proved that the Eta indicator can improve the mean correlation value with the collapse capacity of 84 single degree of freedom structures by approximately 50% (Mousavi et al., 2011). The Eta indicator can be defined as written in Eq. (2).

$$\varepsilon_{Sa}(T) = \frac{\ln\ Sa(T) - \mu_{\ln Sa}(T, M, R, \theta)}{\sigma_{\ln Sa}} \quad (1)$$

$$\eta = \varepsilon_{Sa} - 0.823\varepsilon_{\mathrm{PGV}} \quad (2)$$

where ε_{Sa} and $\varepsilon_{\mathrm{PGV}}$ are the observed spectral acceleration Epsilon and PGV Epsilon respectively; $Sa(T)$ is the GMR spectral acceleration; μ and σ are, respectively, the median and the standard deviation of the spectral acceleration at T which are functions of period, magnitude (M), distance (R) and other seismic properties (θ) and can be obtained using a suitable attenuation model. To demonstrate the importance of both spectral shape indicators a one story building with first period equal to 0.42 s is considered here. The assumed structure is identified as ID 2061 in Haselton and Deierlein (2006) which is designed based on ASCE 7-02 standard. A set of 78 ground motion records are employed as a suitable dataset to

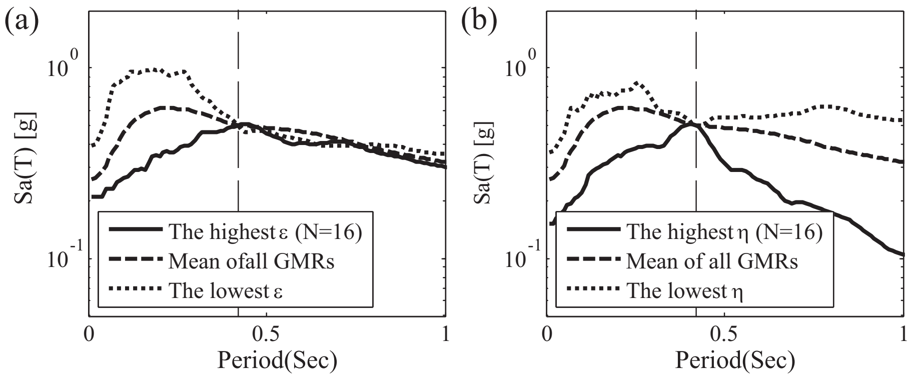

Fig. 2. Comparison of the mean spectrum of 16 GMRs. (a) Highest/lowest Epsilon filtration and (b) highest/lowest Eta filtration.

examine the relationship between Epsilon and Eta with the records spectral shape. The detail characteristics of ground motion records are summarized in Haselton and Deierlein (2006). The Epsilon and Eta values can be calculated for all records in a range of period values by using a suitable ground motion prediction model (e.g. Boore and Atkinson, 2008 in this case). Sixteen records with highest and lowest values for both indicators are sorted and their corresponding mean spectra are shown in Fig. 2. Note that all records are scaled at period of 0.42 s to have the same spectral acceleration value. It is obvious that the mean shape of each set differs while they have the same *Sa* at the period of 0.42 s. Obviously the upper and lower frequency bound of spectra can influence on the response of structures in dynamic analysis. The difference exists for both spectral shape indicators while the Eta indicator can separate the mean of records much more distinctly in comparison with the conventional Epsilon indicator.

2.2. *Correlation of Epsilon and Eta with structural non-linear response*

It is investigated in the previous section that Epsilon and Eta indicators can be robust predictors of the elastic spectral shape. As mentioned before, the Epsilon has also high correlation with non-linear response of structures. It has been shown that the Epsilon is correlated with the structural collapse capacity values (Haselton et al., 2011). To illustrate the robustness of indicators in prediction of non-linear response, the previous assumed structure in Section 2.1 is considered here again. All 78 ground motion records are employed here to assess the response of the given structure through a response-history analysis. To understand the range of demands versus the range of potential levels of ground motions, researchers use a new approach of analysis which is called incremental dynamic analysis (Vamvatsikos and Cornell, 2002). In fact scaling of the GMRs by specific scale factors will be continued up to the collapse of a given structure. Fig. 3a shows the non-linear response of the structure (collapse points) versus Epsilon at $T = 0.42$ s. A simple calculation for the correlation value between two parameter resulted $\rho = 0.57$. In fact the correlation value is meaningful and cannot be neglected. The same approach has been done for the Eta in Fig. 3b. The correlation value is increased up to 0.79 which shows about 40% increment in comparison with the conventional Epsilon. As a result it can be claimed that the Eta indicator is more correlated with the non-linear response of structures in comparison with the conventional Epsilon indicator.

3. The Eta-based conditional mean spectrum

3.1. *Deriving a new target spectrum based on Eta indicator*

The potential of the Epsilon indicator encouraged researchers to use it as a suitable predictor of other spectral acceleration values by a given *Sa* which is representing the target hazard (*Sa* at the period of T_1 on UHRS obtained based on a specific probability of exceedance). For this purpose an effort has been done to introduce a new elastic spectrum that uses the advantages of the Epsilon spectral shape indicator. The conditional mean spectrum uses the correlation between Epsilon values to predict the *Sa* values in the whole range of the target spectrum. The aim of the current research is to introduce the Eta-based conditional mean spectrum as a new target spectrum for the record selection purposes. First it is needed to define a target spectral acceleration value at a period of interest. The period of interest can be computed by modal analysis for a particular structure. Usually the target period is chosen equal to the first mode period of vibration. The mean causal magnitude (M), the mean causal distance (R) and the mean causal Epsilon can be obtained by disaggregation analysis based on the probabilistic

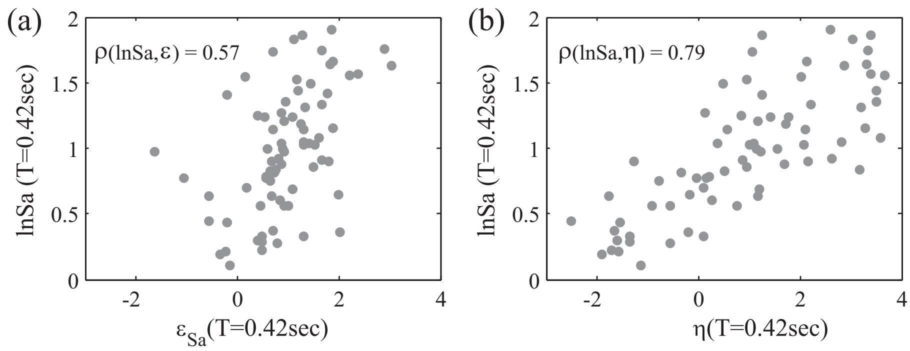

Fig. 3. Scatter plot of the collapse points versus (a) Epsilon values and (b) Eta values at $T = 0.42$ s.

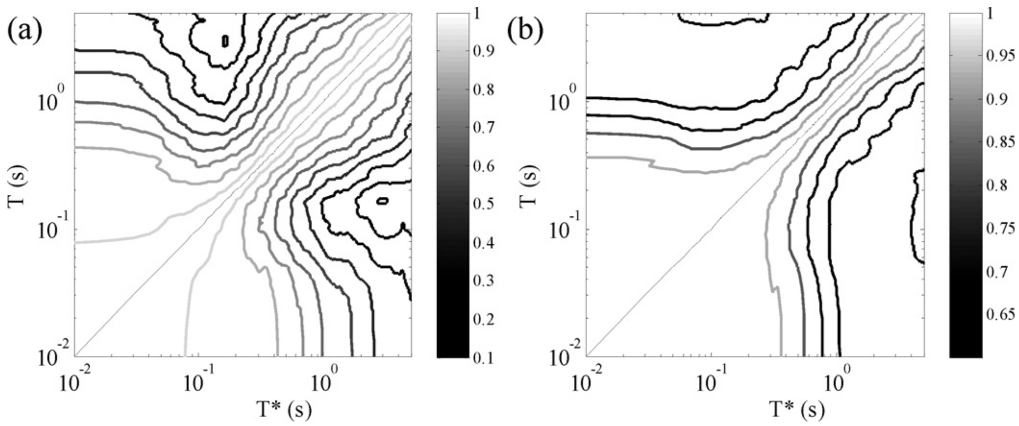

Fig. 4. Empirical correlation coefficients. (a) ρ for Epsilon; (b) ρ' for Eta (T: period of interest, T^*: target period).

seismic hazard analysis. The mean predicted spectral acceleration and the corresponding standard deviation of logarithmic spectral acceleration can be computed using the existing ground motion prediction models (Boore and Atkinson, 2008 in this study). The CMS value in the target period can be calculated easily. The probability calculation shows that the Epsilons in other periods are equal to the original Epsilon value multiply by the correlation coefficient between two Epsilons. The correlation coefficient can be obtained by Baker's prediction equation as a closed-form solution (Baker and Jayaram, 2008), or using the correlation based on a suitable subset of GMRs (e.g. from NGA database). The GMRs used in this study are given in Baker (2005).

The target Epsilon (ε^*) is needed for the conditional computation as well as the target Eta, but the disaggregation analysis only provides the target Epsilon. In fact the target Eta value (η^*) is still unknown. However it is necessary to either perform a new Eta-based disaggregation analysis or normalize the Eta to the target Epsilon in which both can be equal at the target period. For the purpose of simplicity the target Eta value had been normalized to the target Epsilon value in Eq. (3). The target Eta can now be considered to be equal to the target Epsilon which is one of the disaggregation results in addition to the magnitude and distance. The target peak ground velocity Epsilon ($\varepsilon_{\mathrm{PGV}}$) can be obtained as written in Eq. (4) by using Eq. (3). Substituting Eqs. (1) and (4) into Eq. (3) can produce the conditional mean spectrum based on Eta indicator as written in Eq. (5).

$$\eta = 0.472 + 2.730\varepsilon_{\mathrm{Sa}} - 2.247\varepsilon_{\mathrm{PGV}} \quad (3)$$

$$\varepsilon^*_{\mathrm{PGV}} = \frac{1}{2.247}(1.730\varepsilon^*_{Sa} + 0.472) \quad (4)$$

$$Sa(T) = \exp\left(\mu_{\ln\ Sa(T)} + \frac{\eta^*\sigma_{\ln\ Sa(T)}(\rho_{(\eta(T),\eta(T^*))} + 1.730)}{2.730}\right) \quad (5)$$

A correlation model can be employed in order to find ρ values in Eq. (5). Baker and Jayaram proposed a model for the correlation coefficients calculation between the two Epsilon values based on the Chiou and Youngs model. This method is consistent enough with other ground motion prediction models with high level of accuracy. In other words the results have shown that the correlation values do not differ appreciably among the different attenuation models (Baker and Jayaram, 2008). In the current study all parameters including the Epsilon values, the Eta values and the correlation coefficients are computed based on the considered GMR database (Baker, 2005) and BA-08 attenuation model (Boore and Atkinson, 2008) without using any closed-form solution. Fig. 4 shows contours of the correlation coefficient, respectively, between each two arbitrary Epsilon and Eta values. The period range is taken from 0.01 to 5 s in Fig. 4. The Epsilon and the Eta values at other periods can be calculated easily by multiplying the target value by the corresponding correlation coefficient value which can be summarized in Eqs. (6) and (7). For comparison of the two correlation coefficients obtained by Eta and Epsilon values, a new correlation parameter is defined in Eq. (8).

$$\varepsilon(T) = \varepsilon^* \times \rho_{(\varepsilon(T),\ \varepsilon(T^*))} \quad (6)$$

$$\eta(T) = \eta^* \times \rho_{(\eta(T),\varepsilon(T^*))} \quad (7)$$

$$\rho'_{(\eta(T),\eta(T^*))} = \frac{\rho_{(\eta(T),\eta(T^*))} + 1.73}{2.730} \quad (8)$$

This parameter named ρ' expresses the only difference between CMS and E-CMS equations. In fact the parameter ρ' plays the same role as ρ in CMS computation (Eq. (6)). Therefore Eq. (5) can be rewritten as Eq. (9). Here care should be taken that all correlation coefficient values between two sets of observed Epsilon values are evaluated by using the maximum likelihood estimator that is so-called Pearson product-moment correlation coefficient (Kutner et al., 2004) as written in Eq. (10). Next section expresses the properties of the correlations and demonstrates why the Pearson correlation approach is used.

$$Sa(T) = \exp(\mu_{\ln\ Sa(T)} + \eta^*\sigma_{\ln\ Sa(T)}\rho'_{(\eta(T),\eta(T^*))}) \quad (9)$$

$$\rho_{(\varepsilon(T),\varepsilon(T^*))} = \frac{\sum_{i=1}^{m}(\varepsilon_i(T) - \mu_{\varepsilon(T)})(\varepsilon_i(T^*) - \mu_{\varepsilon(T^*)})}{\sqrt{\sum_{i=1}^{m}(\varepsilon_i(T) - \mu_{\varepsilon(T)})^2 \sum_{i=1}^{m}(\varepsilon_i(T^*) - \mu_{\varepsilon(T^*)})^2}} \quad (10)$$

where m is the number of observations (GMRs in this study); $\varepsilon_i(T)$ and $\varepsilon_i(T^*)$ are the Epsilon values at T and T^* respective to the record number i; $\mu_{\varepsilon(T)}$ and $\mu_{\varepsilon(T^*)}$ represent the sample means. Finally the Epsilon-based conditional mean spectrum can be computed based on Baker (2011) and the Eta-based conditional mean spectrum can be obtained by using Eq. (9). It is worth emphasizing that the peak ground velocity Epsilon ($\varepsilon_{\mathrm{PGV}}$) is a period independent parameter. Therefore $\varepsilon_{\mathrm{PGV}}$ is a constant value during a period range for a single record. This fact provides an opportunity to obtain a simple predicting equation as expressed in Eq. (4).

3.2. Joint distribution of spectral shape indicators

Ground motion prediction models represent the probability distribution of well-known intensity measures such as *Sa* at a specified period. However no information can be provided about the correlation between *IMs* at multiple periods. Many efforts have been done for modeling these correlations (e.g. Baker and Cornell, 2006b; Baker and Jayaram, 2008) which are an essential part of some analysis in assessment of seismic hazard or vector-valued probabilistic

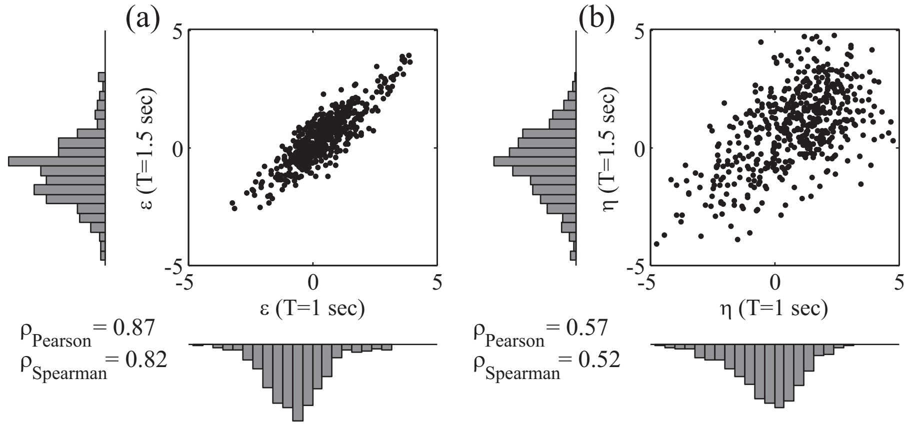

Fig. 5. Distribution of the spectral shape values by employing Campbell and Bozorgnia (2008) attenuation model at $T = 1$ s versus $T = 1.5$ s (a) for Epsilon and (b) for Eta.

seismic hazard analysis (Baker and Cornell, 2005), expansion of custom ground motion models and especially deriving the spectral shape-based target spectrum such as CMS (Baker, 2011).

The calculation of the correlation coefficients depends on the distribution of the variable. The univariate normality of the Epsilon spectral shape indicator is proved before (see Jayaram and Baker, 2008). It is verified that vectors of spectral shape indicators, computed at different sites or different periods, follow a multivariable normal distribution. All correlation coefficients can be computed using the maximum likelihood estimator that is so-called Pearson product-moment correlation coefficient (Kutner et al., 2004). A linear relationship (Pearson correlation) approach is employed here because the Pearson approach is based on the assumption that we have bi-variable normal distribution. In fact use of different correlation approaches depends on the distribution of variables. As shown in Fig. 5 variables are normal or relatively close to bi-variable normal and the obtained correlation coefficient using Spearman or Pearson does not differ appreciably. The data set can be found in Baker (2005). It is worth mentioning that different correlation computation approaches may result in a small differences between the coefficient values, but it will not result in the coefficient equal to unity at other periods than the target period (like UHRS). For the spectral shape computations a ground motion prediction model should be employed inevitably. Therefore an issue may raise that using different attenuation models may influence the results significantly. Baker and Jayaram demonstrated that using different NGA models cannot affect the results (Baker and Jayaram, 2008). For clarify of exposition, comparison of Fig. 5, which is based on CB-08 (Campbell and Bozorgnia, 2008), with Fig. 6, which is based on BA-08 (Boore and Atkinson, 2008), shows that the observed correlations do not vary significantly when the underlying model is changed.

4. Comparing CMS and E-CMS spectra by a simple example

In the performance-based approach described in guide 1.208 (NRC, 2007), the ground motion response spectrum is based on site specific UHRS at the free-field ground surface modified by a design factor to obtain the performance-based site specific response spectrum. The design response spectrum defined in ASCE 43-05 and NRC's GMRs are the same. Both are performance based site specific ground motion response spectrum and can be obtained by scaling the 9950 years return period UHRS. The design factor ensures that site-specific response spectrum is equal to or greater than the mean 1E-04 UHRS. The U.S. Geological Survey (USGS) tool is employed to obtain the design spectra (USGS, 2008). A simple structure located in Riverside with a first-mode period of 0.1 s is assumed, and 1% probability in 100 years is considered as a given hazard level, corresponding to *1E-04* annual probability of exceedance. The median predicted spectral acceleration and the standard deviation values are obtained by BA-08 attenuation model. For the purpose of simplicity, the UHRS is calculated using the predicted median value added by the standard deviation which is multiplied by the target epsilon. This assumption is accurate for single dominated hazard sites and can be an approximate estimate of UHRS for the sites with multiple seismic hazard sources (Ebrahimian et al., 2012). CMS and E-CMS can be derived similarity by consideration of the correlation part. The disaggregation results which are considered as the controlling earthquake parameters, are obtained by employing USGS tool updated in 2009 (USGS, 2008). Fig. 7 shows the disaggregation distribution of magnitudes, distances and Epsilons that will cause the occurrence of $Sa(0.1\,\text{s}) = 2.0255$ g at the assumed site. For conditional computations, by using the BA-08 attenuation relationship, the mean magnitude is equal to 7.15, the mean distance is equal to 10.2 and the mean epsilon is equal to 2.25. These values are obtained as an earthquake scenario which is most likely to cause $Sa(0.1\,\text{s}) = 2.0255$ g. Note that the shear wave velocity averaged over top 30 m is assumed to be 360 m/s. The obtained Epsilon from the disaggregation result is assumed to be equal to the target Epsilon and the other Epsilon values at other periods can be calculated as well. The *Sa* of the conditional mean spectra at the target period is the same as UHRS corresponding to 1% probability of exceedance in 100 years.

Fig. 8a compares UHRS with CMS, E-CMS, and NRC standard spectrum (in Fig. 8b) for the given site. As it is expected CMS, E-CMS and UHRS have the same *Sa* value at period of 0.1 s. The NRC spectrum which is derived by scaling the UHRS has higher amplitudes against CMS and E-CMS as seen in Fig. 8b. Therefore for a better comparison the conditional spectra are scaled in which they have the same *Sa* value (same hazard) at the target period (Fig. 8b). The most interesting finding is that both CMS and E-CMS show a significant reduction in comparison with NRC. It can be concluded that the current NRC leads to a conservative results comparing with the reasonable spectra CMS, and E-CMS.

Another arising issue is the significant difference between the CMS and E-CMS. Both CMS and E-CMS have a peak correlation at period of 0.1 s since the correlation coefficient is high near the target period. The correlation coefficients decrease in large and small periods but the reduction process is more significant in CMS from the target period in comparison with the E-CMS. In other words, E-CMS correlation values in other periods are more than the corresponding CMS values. It is clear that using different ground motion prediction models will result in different predicted median spectrum. In fact CMS and E-CMS will be affected by the attenuation model. However the point is that the observed difference will not change because the source of the difference is somewhere else.

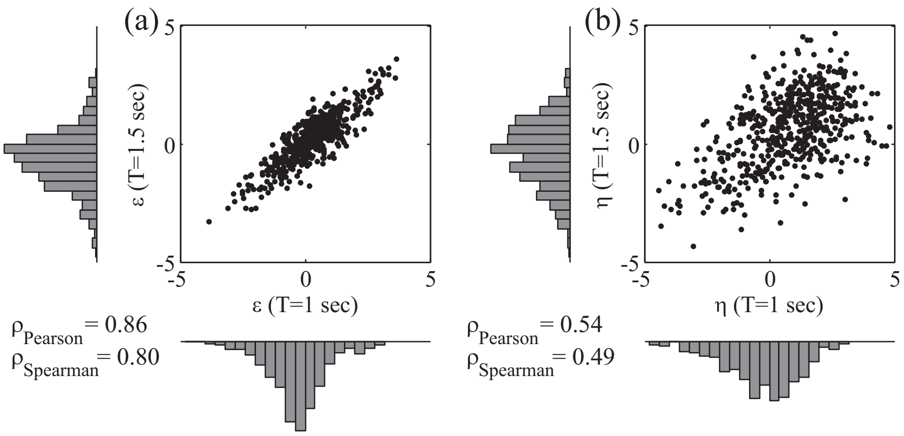

Fig. 6. Distribution of the spectral shape values by employing Boore and Atkinson (2008) attenuation model at $T = 1$ s versus $T = 1.5$ s (a) for Epsilon and (b) for Eta.

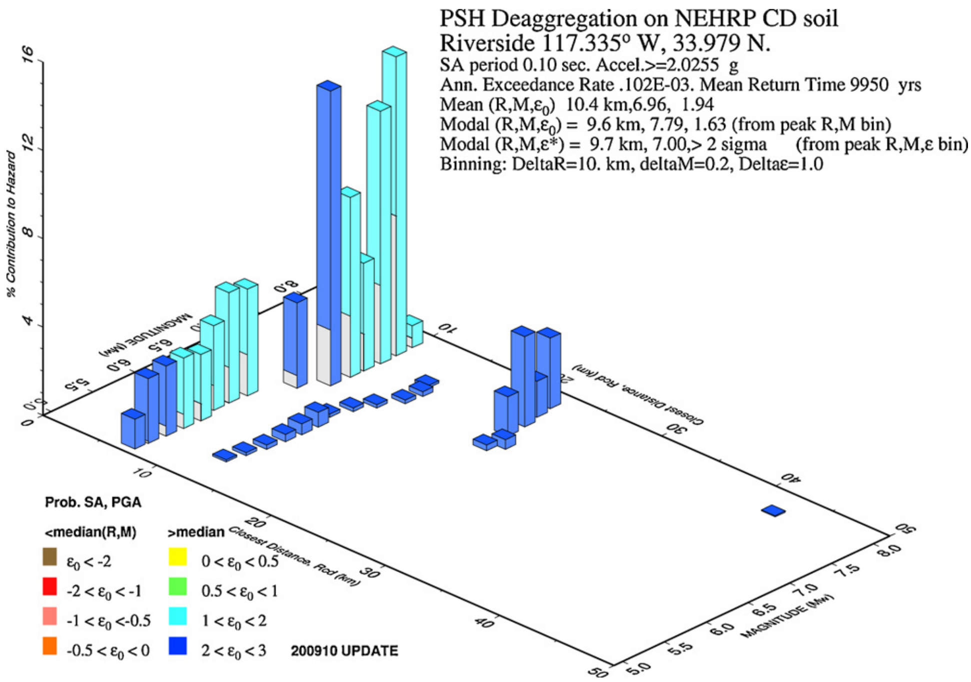

Fig. 7. The PSHA disaggregation, obtained by USGS (2008).

A comparison between CMS, E-CMS and UHRS equations proves that both conditional mean spectra are independent of the spectral acceleration value and the design factor. In other words the source of the difference is only the correlation part. Although the UHRS uses the correlation coefficient equal to unity for all periods, but both of the conditional mean spectra take the correlation of the spectral values into account. This fact is also shown in Fig. 9a where the parameter ρ' for Eta and ρ for Epsilon are compared versus

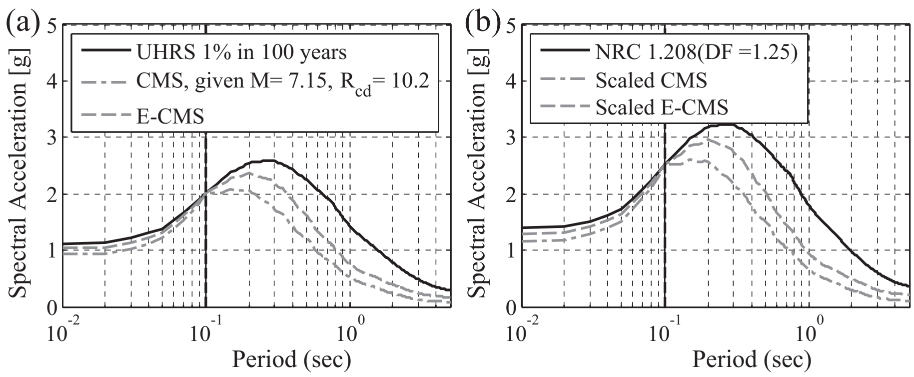

Fig. 8. (a) Comparison of the UHRS, CMS, E-CMS for 9950 years return period; (b) NRC standard spectrum versus scaled CMS and scaled E-CMS.

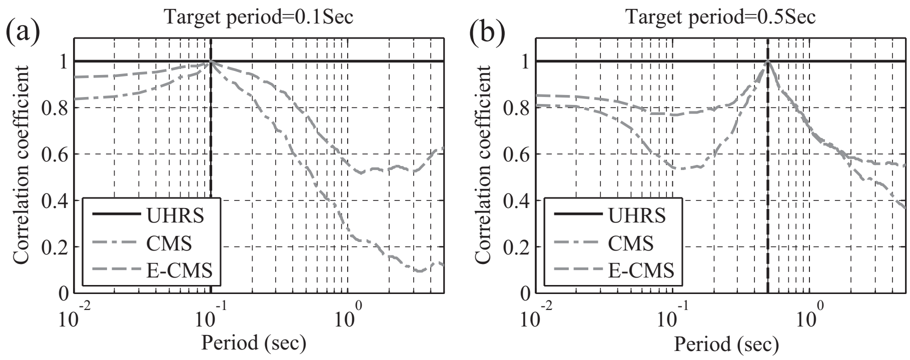

Fig. 9. The correlation coefficients over a period range; (a) target period = 0.1 s; (b) target period = 0.5 s.

UHRS. Note that Fig. 9a shows the correlation values, and do not reflect the spectral acceleration terms. In other words Fig. 9a can justify the differences between CMS, E-CMS and UHRS since CMS is based on ρ and E-CMS is based on ρ'. As a result it is not important what the attenuation model and the design factor are, because the difference is just sourced by the correlation values. Fig. 9b shows the correlation values at another target period (T = 0.5 s).

The higher correlation values between the Eta and the structural response, compared with the corresponding correlation between the Epsilon and the structural response which has been shown briefly in this study (see more details in Haselton and Deierlein, 2006), is a significant logic that E-CMS is more realistic rather than CMS. However, it is worth to exploring this issue from different viewpoints in a more detailed study. As a concluding statement, authors emphasize that using E-CMS as an alternative of the current nuclear standard spectrum e.g. NRC can lead to more realistic assessment of the structural response.

5. Conclusion

Ground motion selection based on target spectra is currently a timely subject in earthquake engineering society. Therefore considerable efforts have been done to propose a realistic approach to obtain the target spectra. The UHRS, as a result of probabilistic seismic hazard analysis, is the most popular approaches in the design standards since all of the ordinates in UHRS spectrum have a same hazard level. The conditional mean spectrum is one of the recent developments for this purpose which employs the advantages of using the correlation between the spectral values. A new target spectrum, named E-CMS, has been introduced in this paper which uses the Eta indicator advantages and follows the CMS format. The conservation in the estimation of the structural seismic response can be reduced by using the E-CMS since the correlation of Eta and the structural response is greater than the correlation between the conventional epsilon and the structural response. However the conventional CMS can underestimate the structural response. Therefore the E-CMS is introduced as a realistic target spectrum which can be used in the design procedures of nuclear facilities.

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