Research Paper

Implementing the Use of Conditional Mean Spectrum (CMS) in the Zagros Region

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ABSTRACT

This paper aims at implementing and introducing the use of conditional mean spectrum (CMS) as the main input parameters in the practice of seismic safety evaluation in Zagros, instead of the used uniform hazard spectrum (UHS). The CMS has been proposed as an alternative to the UHS to be employed as a target spectrum in ground motion record selection. The CMS provides the expected response spectrum, conditioned on occurrence of a target spectral acceleration value at the period of interest. For this purpose, a procedure for M-R-epsilon seismic hazard deaggregation in Zagros was first developed. The results indicate that by selecting high periods as the target period, the difference between the uniform risk spectrum and the conditional mean spectrum increases. Thus the shape of the conditional mean spectrum is more sensitive to tall structures. In fact, the shape of these spectra is highly dependent on the target period. This point is more important in the dynamic analysis of structures with several degrees of freedom. Considering only one period of target rotation in these structures obtains underestimated results. In the conditional mean spectrum, the closer the two cycles are to each other, the higher the correlation of the epsilon values and the less scatter. This means that the farther apart the two rotations are, the less similar the spectral acceleration values are to each other.

Keywords:
Seismic Hazard Analysis; CMS; Seismic safety evaluation; Zagros; Iran

1. Introduction

The selection of ground motion time series provides the critical link between site-specific probabilistic seismic hazard analyses (PSHAs) and dynamic seismic response analysis to quantify the seismic performance of a system of interest. By the use of conditional mean spectrum, ground motions can be selected for dynamic seismic response analyses of engineered systems when the underlying seismic hazard is quantified via ground motion simulation rather than empirical ground-motion prediction equations. Even with simulation-based seismic hazard, a ground motion selection process is still required in order to extract a small number of time series from the much larger set developed as part of the hazard calculation.

The Conditional Mean Spectrum (CMS) has been recently developed by Baker and Cornell [1] 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 UHS.

The CMS was proposed by Baker and Cornell [1] to take account of the correlation of spectral demands, represented by values of epsilon (ε), at different periods [2]. To properly consider the aleatory variability in the response spectrum, an extension of the CMS, i.e., conditional spectrum (CS) distribution, was proposed by Jayaram et al. [3] and Lin et al. [4]. The structural response prediction is often obtained by selecting ground motions that match some corresponding target response spectrum, and using those ground motions as input to dynamic analysis. An alternative, termed a Conditional Mean Spectrum (CMS), provides the expected (i.e., mean) response spectrum, conditioned on occurrence of a target spectral acceleration value at the period of interest. It is argued that this is the appropriate target response spectrum, and is thus a useful tool for selecting ground motions as input to dynamic analysis. The CMS will describe, its advantages relative to the UHS will explain. Recent work illustrating the impact of this change in target spectrum on resulting structural response is briefly summarized.

2. Methodology

To investigate the effect of the new correlation coefficients on the CMS spectrum, a large national and important structure of the country, namely Bakhtiari Dam in the Zagros region has been selected. This arched dam is under construction on the Bakhtiari River, a tributary of the Dez River, in the Zagros Mountains located in Lorestan Province (Figure 1).

Seismic hazard analysis and deaggregation of seismic hazard analysis have been performed for this dam using EZ-frisk program and spectral accelerations resulting from PSHA for the 475 years return period using two attenuation relations of Campbell-Bozorgnia [5] CB2008 and Boor-Atkinson [6] BA2008 is calculated (Figure 2).

According to the dynamic characteristics of the structure, the main period of its first mode is equal to 1 s, which is the basis for future calculations of the CMS of this Period. Figures (3), (4) and Table (1) provide information on the seismic deaggregation of this structure in the Zagros region.

A database consisting of 241 specific strong motion data in the Zagros region after the necessary corrections and processing of data, response spectra have been calculated. Information about the specifications of the selected data is given in Table (2). Using these two attenuation relations

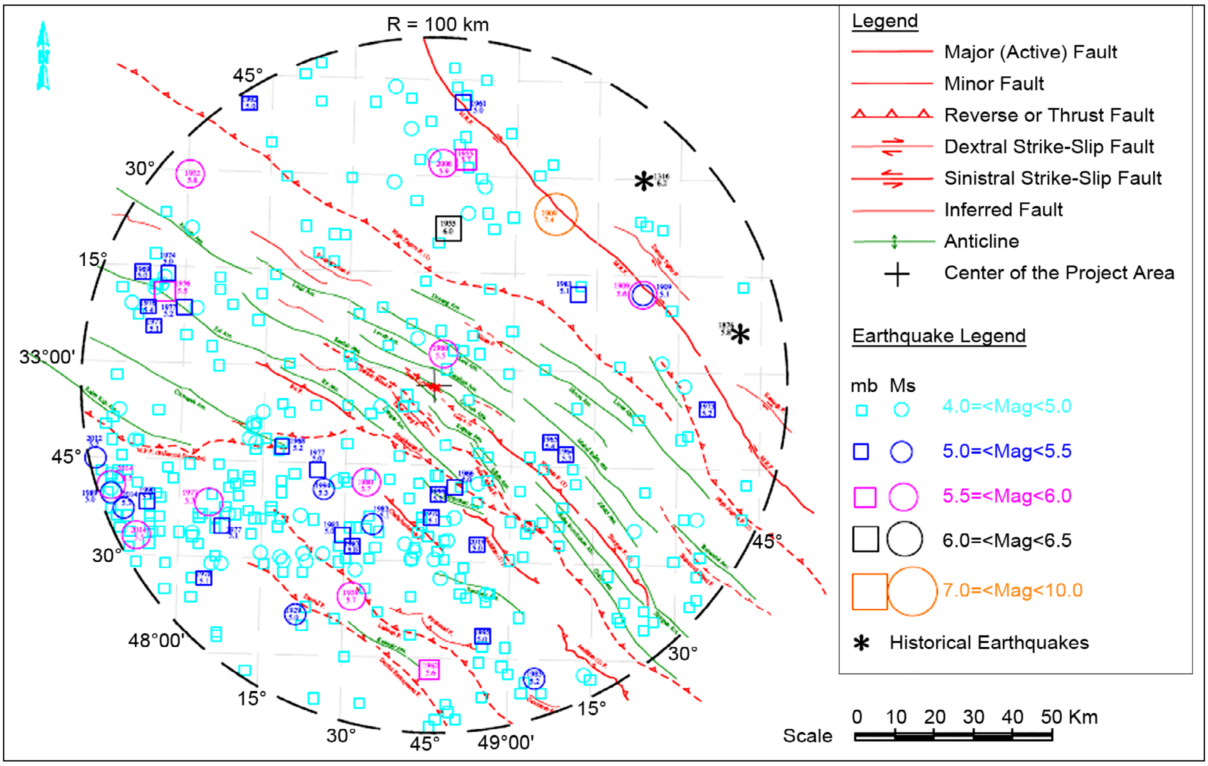

Figure 1. Seismotectonic map of the under-study area of Zagros region with radius of 100 km.

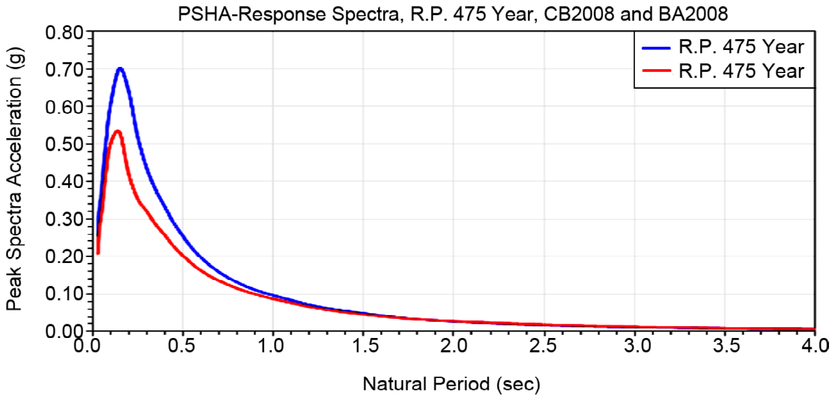

Figure 2. Response spectra derived from PSHA method in Bakhtiari dam site with the use of BA2008 & CB2008 attenuation relations, for the R.P. of 475 years.

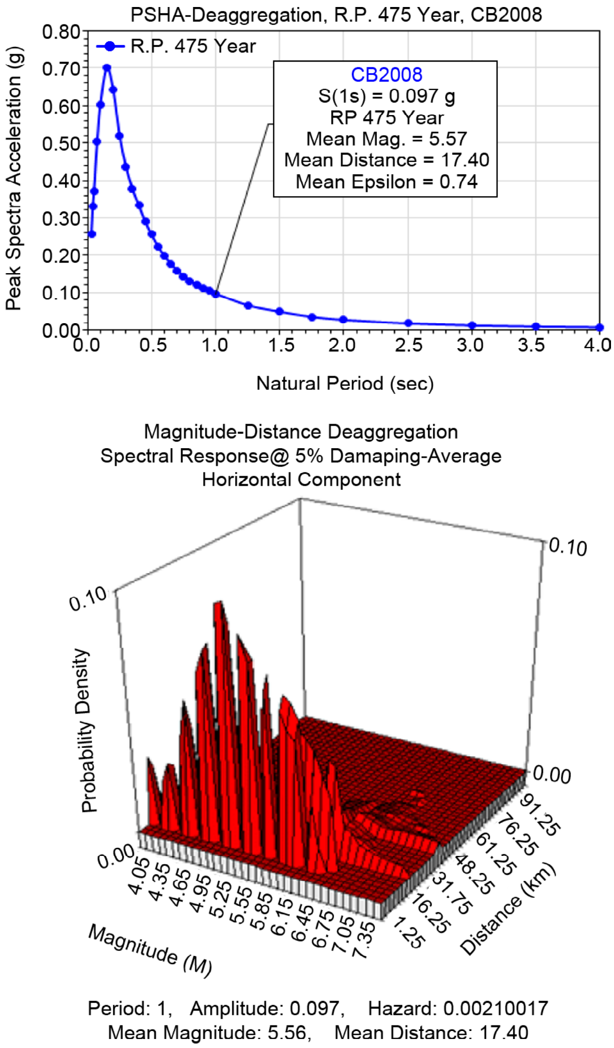

Figure 3. Seismic deaggregation by PHSA method in Bakhtiari dam site with the use of CB2008 attenuation relation, for the R.P. of 475 years.

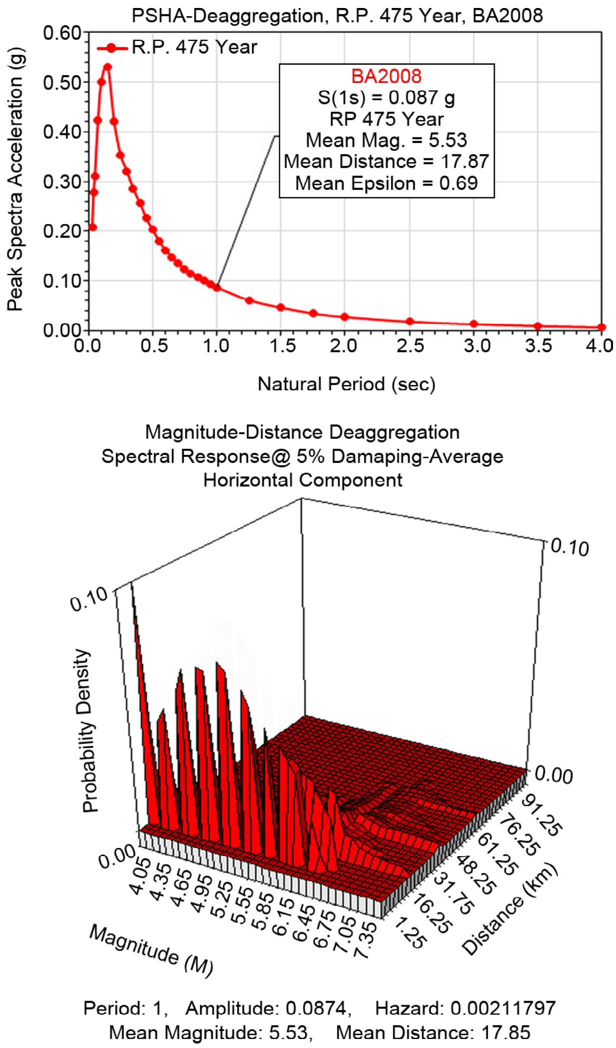

Figure 4. Seismic deaggregation by PHSA method in Bakhtiari dam site with the use of BA2008 attenuation relation, for the R.P. of 475 years.

Table 1. Information obtained from the seismic deaggregation at the Bakhtiari dam site.

GMMs	BA2008	CB2008
Sa (T=1s) (g)	0.087	0.097
Mean Magnitude	5.53	5.57
Mean Distance (km)	17.85	17.4
Mean Epsilon (ε)	0.69	0.74

(BA2008 & CB2008), the ε is calculated for the different periods (0.04 to 4.00 sec) of these records and is shown in Figure (5).

By calculating the value of the parameter ε for different periods, the response spectrum of all ground motion data is measured using the correlation coefficient ratio of the correlation of this parameter at different periods for all data. For example, the scattering of ε values in the main period (T^* = 1s) of each record was compared with ε in 0.04, 0.5, 2, and 4 s periods of the same record shown in Figure (6).

Table 2. Information about the specifications of the selected data.

Parameter	Range
R (km)	1.1 ~ 70
Fd (km)	6 ~ 50
Ms	3.8 ~ 7.3
Vs (m/s)	281 ~ 1500
Date	1985 ~ 2018

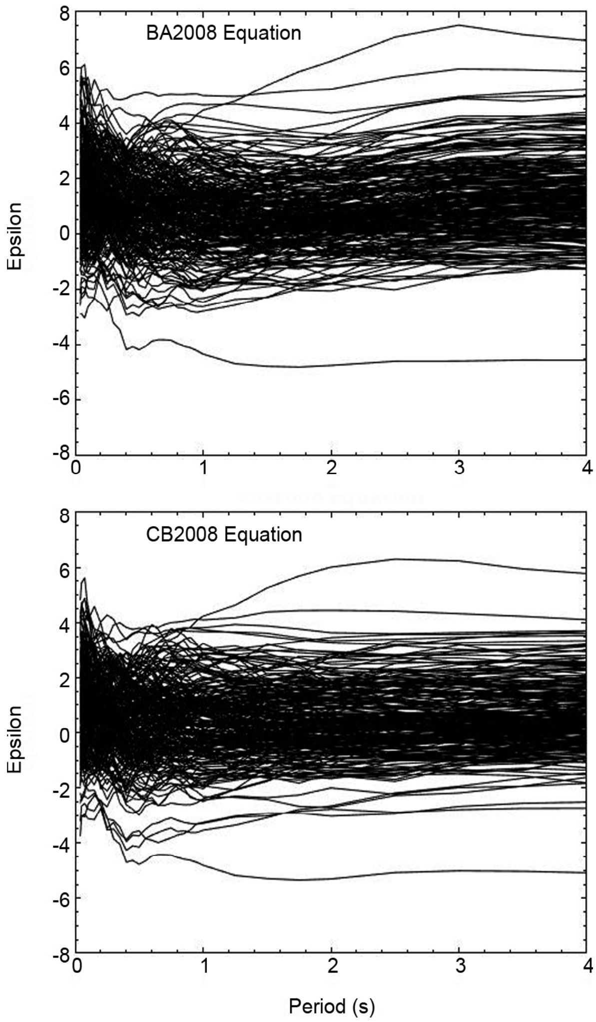

Figure 5. ε-curves of natural records with the use of BA2008 & CB2008 attenuation relations, in periods of 0.04 to 4.00 s.

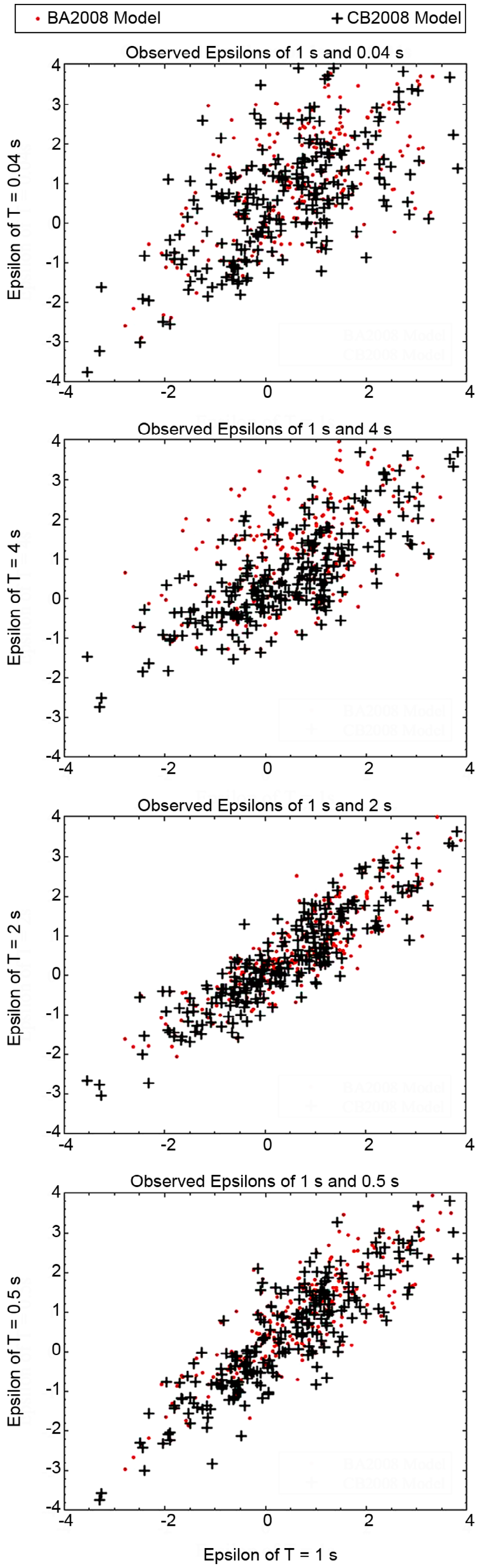

Figure 6. The scattering of ε values in the main period (T* = 1s) of each record was compared with ε in 0.04, 0.5, 2, and 4 s periods of the same record.

3. Correction of the Correlation Coefficients

By obtaining the correlation of ε's in different periods, it is possible to modify the coefficients introduced in the older Baker 2006 and 2008 relationships. An effective method for selecting the best coefficients is to change the coefficients incrementally from zero and calculate the sum of squared errors introduced relationship to estimate the correlation coefficients (Equation 1) with the new coefficients.

$$\rho\left(\varepsilon\left(T_{min}\right),\varepsilon\left(T_{max}\right),C_1,C_2,C_3\right)=$$

$$1-\cos\left(\frac{\pi}{2}-\left(C_1+C_2\, I_{\left(T_{min}<0.189\right)}\ln\frac{T_{min}}{C_3}\right)\ln\frac{T_{max}}{T_{min}}\right) \quad (1)$$

By changing coefficients C_1, C_2, C_3 the sum of squared errors (*SSE*) from Equation (2) will be calculated:

$$SSE=\sum_{i=1}^{n}(\rho\left(\varepsilon\left(T_{min}\right),\varepsilon\left(T_{max}\right),C_1,C_2,C_3\right)-$$

$$\rho\left(\varepsilon\left(T_{min}\right),\varepsilon\left(T_{max}\right)\right)_{Zagros})^2 \quad (2)$$

For each set of combinations C_1, C_2, C_3 where the error value of the above relation is the lowest, the value of these coefficients is introduced as new constants. By performing the above process as software on the selected real accelerometric data in Zagros, new constants are obtained as described in Table (3).

By modifying the constant coefficients C_1, C_2, C_3 of the Baker [7] correlation relation and introducing new fixed coefficients for this relation, the values of the correlation coefficients $\varepsilon(T_1)$ vs. $\varepsilon(T_2)$ for the set of natural ground movements in the Zagros region, using two relations. The selected attenuation of CB2008 and BA2008 is calculated in the range of 0.04 to 4 seconds and their results are shown in Figure (7) for before and after correction of coefficients.

Table 3. New fixed coefficients C_1, C_2, C_3 from Baker and Cornell [1] correlation relationship for the set of natural records in Zagros region, using CB2008 and BA2008 relations.

Coeff.	BA2008	CB2008	Baker and Cornell (2006)
C_1	0.189	0.169	0.359
C_2	0.076	0.100	0.163
C_3	0.110	0.068	0.189

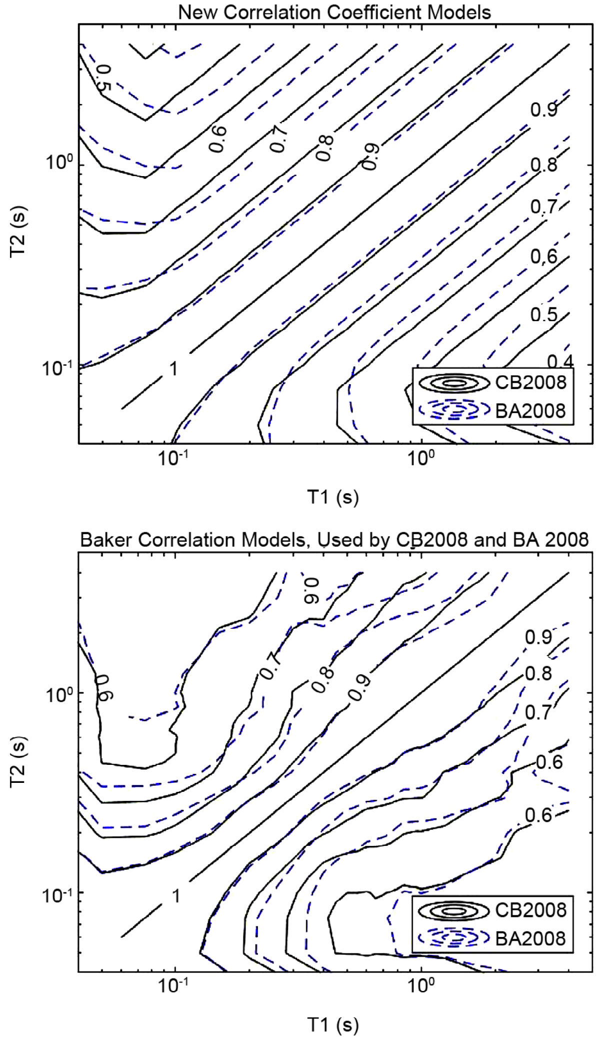

Figure 7. Comparison of correlation coefficient curves against T1 and T2 periods, before and after correction of fixed coefficients of Baker and Cornell [1] using CB2008 and BA2008 relations, for a set of selected natural ground motions in Zagros region.

As expected, the correlation rate obtained from natural and specific records of Zagros study area is higher than the values obtained from the old experimental relationships and by estimating the new constant coefficients C_1, C_2, C_3, the prediction diagrams of correlation coefficients (ρ) versus period T_1, have become smoother and more stable.

4. Calculation of Conditional Mean Spectrum (CMS)

Figure (8) shows the response spectrum from PSHA and the conditional mean spectrum (CMS). As it is known, by using the modified coefficients, the response spectrum at smaller periods shows larger values than the general relation given above,

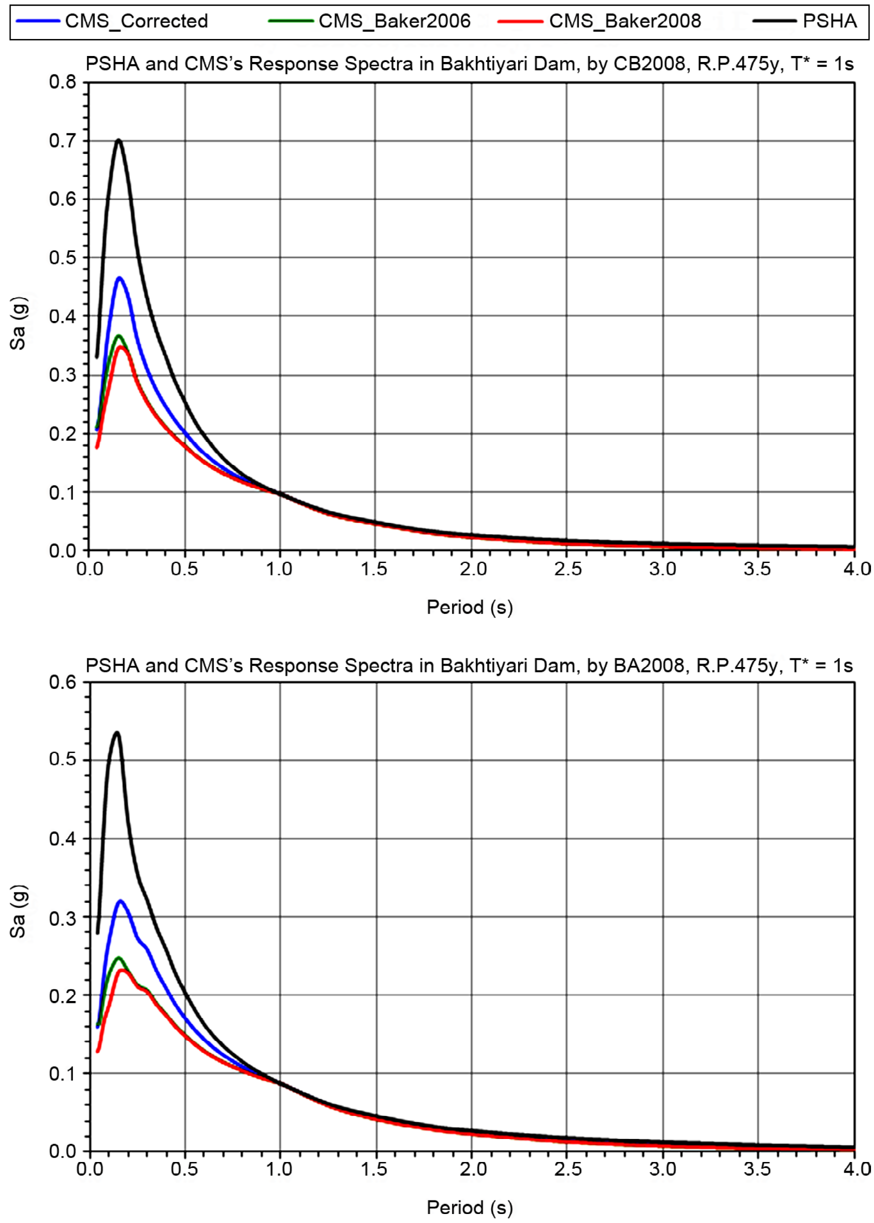

Figure 8. Response spectrum of probability seismic hazard analysis (PSHA) and the estimated conditional mean spectra (CMS) for the Bakhtiari Dam site, based on the Baker and Cornell [1] and Baker and Jayram [2] experimental and modified correlation relationships using the CB2008 & BA2008 attenuation relationship.

which are larger economically, the required costs are not approved.

Figure (8) shows the diagrams of the response spectra from the probabilistic hazard analysis (PSHA) and the conditional mean spectra (CMS) for T^* = 1s (natural period of the structure) and the return period of 475 years, based on the old and new correlation relationships for the CB2008 & BA2008 attenuation relationships is provided for a better comparison of results.

One of the goals of the manuscript is to show that CMS is more suitable than other spectrums and it can be seen in Figure (8) that CMS has higher values than other spectrums. The reason for the lower values of CMS compared to the Bakers' spectrum, is the kind of data bank. It is quite conceivable that the number of large events in the worldwide database is much higher than in this database. On the other hand, it has been proven that the values of correlation between different spectral values are influenced by magnitude [8]. Therefore, the decrease in correlation between different spectral values in the model developed compared to the original model originates from this point.

By modifying the constant coefficients of the correlation relation, the conditional-response spectrum in the lower periods shows larger values than other correlation relations, which include various reasons such as the type of attenuation relation, number, and variety of database acceleration data, construction conditions, etc.

5. Conclusion

Conditional Mean Spectrum (CMS) provides the expected (i.e., mean) response spectrum, conditioned on occurrence of a target spectral acceleration value at the period of interest. On the other hand, Epsilon (the normalized difference between the spectral acceleration of a recorded ground motion and the median response predicted by a ground motion prediction equation) in probabilistic seismic hazard disaggregation, has a very impressive effect on this spectra.

In the conventional mechanism of probabilistic analysis of the structural seismic response, the acceleration response spectrum in a particular period (specifically the period corresponding the first mode of the structure) is selected as a scalar intensity measure that links the seismic hazard and structural response analyzes. The adequacy of using a scalar value as an intermediate link is always in question and causes bias in probabilistic response analysis. This bias leads to conservative estimation of the response, especially at higher levels of seismic hazard. On the other hand, using the vector intensity measure greatly increases the complexity of calculations and will not be able to be introduced as a comprehensive method among practitioners. The conditional mean spectrum (CMS) is an innovative solution hypothesized by Baker [9] aimed to implicitly reduce the bias mentioned in the probabilistic analysis.

In this research, a series of time series specific to the Zagros region have been collected. For this data, the values of ? and their correlation are calculated. According to past relationships, the correlation resulting from this data is higher than the values presented in the empirical relationships. This increase in correlation means that if, for example, the period of 1 s has high spectral acceleration, the rest of the periods have high values. Therefore, the CMS obtained from this high correlation also has higher values. This increase in spectral acceleration directly affects the selection of data corresponding to the CMS and is especially effective at smaller periods. For short period structures, the choice of correlation relationship can have a significant effect on the final response spectrum. As expected, the choice of the attenuation relationship also has little effect on the values of the correlation created by earth movements.

For structures with a high level of importance and hazard, such as dams and power plants, this CMS conditional spectrum can be a good estimate of the seismic response of the structure and will be not only more compatible with the seismicity conditions of the study area but also in seismic design and the dynamic analysis of the structure provides the designers with the most appropriate records of ground motions as the seismic load on the structure. It is obvious that economically, reducing the amount of design acceleration will automatically reduce the current costs of the design. Therefore, the optimal selection of design response spectra will involve the optimal cost of constructing structures.

Acknowledgment

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