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**PROBABILISTIC SEISMIC HAZARD ANALYSIS IN THE REGION OF KHUZESTAN  
PROVINCE AND DETERMINATION OF UNIFORM HAZARD SPECTRA BASED ON  
SPECTRAL ACCELERATION HAZARD ZONATION MAPS**

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**ABSTRACT**

The first step towards establishing a structure or strengthening the existing structures against earthquake hazards is to have an appropriate estimation of the likely forces caused by the earthquake. Nowadays, the only existing method to get the estimation is the use of a probabilistic framework called probabilistic seismic hazard analysis. In this study, an attempt has been made to apply four different spectral attenuation relationships to calculations of probabilistic seismic hazard analysis and also to use surface models to define seismic sources to prepare maps of peak ground acceleration and spectral acceleration in different periods and probabilities of occurrence for Khuzestan province region. Based on the maps, horizontal uniform hazard spectra have been determined. The effect of applying various attenuation relationships to seismic hazard analysis calculations which leads to variability of form and values of spectral magnitude of uniform hazard spectra indicates the necessity of selection of appropriate attenuation relationships for seismic hazard analysis in a region.

**Keywords: Earthquake, Uniform Hazard Spectrum, Probabilistic Seismic Hazard  
Analysis, Spectral Attenuation Relationships, Khuzestan**

## INTRODUCTION

Earthquake is an indicator of continuous movement of Earth's crust and is regarded as one of the most destructive natural phenomena which make a large number of people involved in its adverse effects in different parts of the world every year. An undeniable reality which should be accepted is that with the current human's knowledge, it doesn't seem that there exists any way but designing earthquake resistant structures and strengthening existing structures to deal with the natural phenomenon. Undoubtedly, the first step for this issue is nothing but to analyze and evaluate earthquake hazards and get an appropriate estimation of earthquake forces. In other words, all these facts are proofs of the importance of the studies in which the earthquake hazard is analyzed and evaluated and naturally the present paper is part of the studies. On the other hand, Iran is an earthquake-prone country where multiple cases of destructive earthquakes have occurred and each left irreparable damages and losses. Iran plateau being located in orogeny belt of Alps-Himalaya as the most seismically active regions in the world, and also other geological, seismic, seismological and geophysical evidence all indicate that there is always the probability of occurrence

of another severe earthquake in the region of Iran [1].

However, what sometimes doubles the necessity of performing such studies is the importance of the selected target area of the study. Without any doubt, Khuzestan province is viewed as the palpitating heart of Iran's economy and the lifeblood for its industry. Since a large part of the country's infrastructure such as refineries, oil and petrochemical installations and very large dams as well are located in the province, some of which are constructed in seismic regions, the necessity of dealing with the issue of earthquake hazards in the province is demonstrated more than anything else.

Complexity of natural phenomena in general and specifically a phenomenon like the earthquake has caused such phenomena not to be controllable and the location and magnitude of future earthquakes not to be predictable with the current knowledge. In such circumstances, application of the science of statistics and probabilities will probably be the only possible and functional option to analyze such phenomena. Combining probabilistic concepts with geotechnical seismic science, the method of Probabilistic Seismic Hazard Analysis has been developed which is viewed as the most

common, comprehensive and paramount approach for seismic hazard assessment. The goal of probabilistic seismic hazard analysis is to estimate logically the occurrence probability of parameters that are dependent on the ground movement in a specific location [2].

In seismic hazard analysis, attenuation relationships are viewed as key elements. One of the results of applying spectral attenuation relationships in seismic hazard analysis calculations is the determination of Uniform Hazard Spectrum. Uniform hazard spectrum is a response spectrum with uniform occurrence probability in all points of its domain in various periods. In other words, uniform hazard spectrum is a collection of separate points where all these points have been calculated for the same occurrence probability [3].

With such a background, the objective and importance of the present study can be explained easily. In this paper, it was attempted to use probabilistic seismic hazard analysis method to evaluate the earthquake hazard in the region of Khuzestan province. In this study, having defined the project and target area (Khuzestan province), the existing faults in the project area, which may somehow influence on the region of Khuzestan province, were identified. In

addition, having determined the condition of seismic activity of the project area, the necessary models for seismic sources were defined and used in probabilistic seismic hazard analysis to produce the desirable results which are peak ground acceleration maps and spectral acceleration maps in several periods and various occurrence probabilities. Using the maps, the maximum, average and minimum values of the parameters were determined to make uniform hazard spectra. In this study, during the course, maximum, average and minimum horizontal uniform hazard spectra were presented using four different spectral attenuation relationships at two levels of occurrence probability. In the end, comparing the results obtained from seismic hazard analysis, the effect of the change in spectral attenuation relationships on the form and magnitude of horizontal uniform hazard spectra can clearly be observed.

### **1- Definition of the target area, project area and its seismotectonic situation**

The target area of the study includes seismic regions of Khuzestan province. Accordingly, the area ( $47.70^{\circ}$  E- $50.70^{\circ}$  E;  $30.00^{\circ}$  N- $33.00^{\circ}$  N) was defined as the target area. In order to analyze the seismic hazard in the area, a widespread area of ( $47.00^{\circ}$  E- $51.00^{\circ}$  E;

30.00° N-34.00° N) was considered and all of its seismic factors, that is existing faults which may somehow affect the target area, were identified (figure 1). In order to gain a correct view of the seismic situation of the area of Khuzestan province, the area was divided into a grid of 0.05°×0.05° points and calculations of probabilistic seismic hazard analysis were performed for all the grid points. Nearly all the surface of the project area selected in the project belongs to Zagros seismotectonic state. The major seismic hazard of Khuzestan province is also related to the seismic activities of the state sources. The region seismicity features are functions of Zagros seismotectonic features.

According to the conducted studies, some of the faults located in the project area have been identified well, but there is little accurate information about the others. Of the most important identified faults in the project area, mountain front fault (simple folded Zagros border with foothills and coastal plain of Persian Gulf, which itself consists of numerous faults with lengths of 15 to 115 km and seismic faults of Behbahan, Teshan, Indica and Balarood are in fact parts of it), Dezful Foroobar fault (northern border of Dezful Foroobar which lies between thrust faults of mountain front and southern Zagros and consists of Lahbari, Dezful and

Ramhormoz sections), Ahvaz fault (with an approximate length of 60 km in the south of Khuzestan province center which has probably been the cause of the historical and destructive earthquake of Ahvaz in 218 solar Hijri), Aghajari fault (with an approximate length of 150 km) and Maroon fault (with an approximate length of 50 km) can be mentioned. In figure 1, epicenters of the area together with the target area and location of existing cities have been illustrated.

Such a map can be a suitable basis to define and model nine surface seismic sources of the area (figure 1). According to the map and in an overall judgment, based on the existing faults and the statistics of earthquake occurred, it can be said that the relative level of seismic hazard in the northern part of Khuzestan province is high. Anyway, in order to perform calculations of seismic hazard analysis, device earthquakes collected from authentic references [4] were combined with historical earthquakes [5] and having done the necessary modifications such as elimination of aftershocks and foreshocks by the spatial and temporal windows method [6], magnitude integration, determination of the year of catalogue completion etc., the final earthquake catalogue was prepared and using it, seismic parameters such as seismic activity rate, seismic coefficient and the

maximum seismic potential was calculated for the faults modeled as linear geometry.

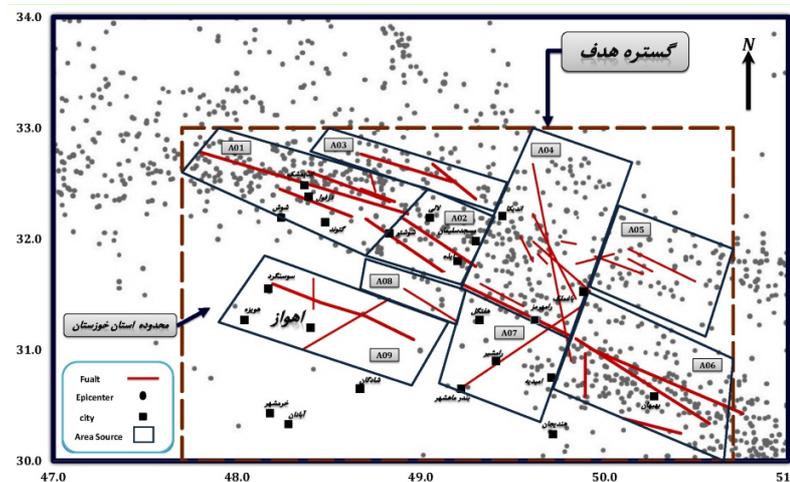


Figure 1: Definition of target area, project area, identification of main existing faults and illustration of surface seismic sources and epicenters of the project area

### Selection of appropriate spectral attenuation relationships for probabilistic seismic hazard analysis

In seismic analysis, attenuation relationships are regarded as a key element. Attenuation relationship is a mathematical relation which describes one parameter of ground movement in terms of various parameters such as largeness, distance, various terms of site and probably other variables. The general form of an attenuation relationship can be as follows:

$$Y=f(M,R,C_i) \quad (1)$$

where Y is the desired parameter of the ground movement. The difference between a spectral attenuation relationship and an attenuation relationship is that the former describes a spectral parameter like spectral acceleration instead of ground movement parameters. Therefore these relationships can directly be used for making a spectrum. In

order to evaluate seismic hazards, selecting an appropriate attenuation relationship is of great importance. The most important factor for selecting a spectral attenuation relationship for a zone is then consideration of seismotectonic conditions of the zone. Therefore a relationship is suitable for a region when the information registered in the same region is used to make it. According to the general condition, four authentic spectral attenuation relationships were used for Khuzestan region to analyze the seismic hazard in the study. The four spectral attenuation relationships are:

- 1- The spectral attenuation relationship proposed by Ambraseys, Simpson & Bommer (1996)
- 2- The spectral attenuation relationship proposed by Zare (1999)

3- The spectral attenuation relationship proposed by Khademi (2002)

4- The spectral attenuation relationship proposed by Zare and Sabzali (2006)

The first relationship was proposed by Ambraseys et al, which is called ASB hereafter, in 1996 as follows [7]:

$$\text{Log}(y) = C_1' + C_2M + C_4 \cdot \text{Log}(r) + C_A \cdot S_A + C_S \cdot S_S + \sigma(T) \cdot P \quad \dots \dots \dots (2)$$

where y, M and r is respectively the spectral acceleration, surface waves magnitude and an indicator of distance, which is defined as follows:

$$r = \sqrt{d^2 + h_0^2} \quad \dots \dots \dots (3)$$

D is the distance from the site to its surface fault.  $h_0$  is a constant whose value differs for varying periods.  $\sigma$  is the standard deviation and an indicator of data distribution around the mean. In the relationship, if  $P=0$ , then the average state dominates and if  $P=1$ , then the ultra-average states  $S_A$  and  $S_S$  control the site conditions and can be zero or one depending on the site conditions. Coefficients of the relationship which are

$$\log(Sa(T)) = a(T) \cdot M + b(T) \cdot R - \log(R) + C_i S_i + \sigma \cdot P \quad (4)$$

Where the coefficients of the relationship are proposed for various periods as coefficient a, coefficient b, four C coefficients and standard deviation of  $\sigma$ . In the relationship, M is the moment magnitude of the earthquake and R is the distance from the epicenter of the earthquake. In addition,

$$Y = C_1 \cdot \exp(C_2 \cdot M)(R + C_3 \cdot \exp(C_4 \cdot M))^{C_5} + C_6 \cdot S \quad \dots \dots \dots (5)$$

Where Y is the desired parameter (ground acceleration or spectral acceleration in terms

calculated for various periods are introduced as C values. The spectral attenuation relationship is usable for Europe and the Middle East and the reason for selecting the relationship is the use of a number of accelerograms which were registered in Iran to produce the relationship.

The second relationship was proposed by Dr. Zare in 1999 as follows [7]:

the parameter P can be used to define the average or ultra-average states while S variables are used to define various site conditions which are considered as rock site condition in this study.

The third relationship was proposed by Mr. Khademi in 2002 as follows [7]:

of g), M is the magnitude and R distance to the fault in terms of kilometers. The

magnitude used in the relationship is of the moment magnitude type. The parameter S is a zero and one variable which controls the site conditions. If s is equal to zero, then rock site conditions dominate and if it is equal to one, soil site conditions are

$$\text{Log}(S_a(T)) = a_1(T).M + a_2(T).M^2 + b(T). \text{Log}(X) + C_i(T).S_i + \sigma(T).P \dots \dots (6)$$

Where  $S_a(T)$  is the spectral acceleration in period T and in terms of g. The magnitude M used in the relationship is of moment magnitude type and the distance X defined for the model is the distance from the epicenter. Coefficients  $\{a_1(T), a_2(T)\}$  and  $b(T)$ , which are respectively coefficient of magnitude and non-elastic attenuation coefficient, are parameters dependent on period and are defined for different periods. The value of  $\sigma(T)$  is the standard deviation of logarithm of the spectral acceleration in period T. It is apparent that if P is selected as zero, the relationship will be in the

$$P[Y > y] = P[Y > y | X] f_x[x] dx \dots \dots (7)$$

Where X is a vector indicator including all random variables affecting Y and  $f_x$  is a function of probability density function type which shows the uncertainty of the random variable. The two variables of distance (R)

$$P[Y > y] = \iint P[Y > y | m, r] f_M(m) f_R(r) dm dr \dots \dots (8)$$

Where  $P[Y > y | m, r]$  is the same as attenuation relation and  $f_M(m)$  and  $f_R(r)$  are

established. In this study, rock site condition is considered. Values of coefficients  $C_1$  to  $C_6$  are calculated for different periods.

The last relationship was proposed by Dr. Zare and Sabzali in 2006 as follows [7]:

average state and if it is equal to one, the ultra-average state will govern, which corresponds to occurrence probability of 84.1%. Values of  $C_i(T)S_i$  control various site conditions in the attenuation relationship.

**2- method of estimation of seismic hazard**

The method that is used to estimate the seismic hazard associated with a site is adopted from a known rule of probabilities science, which has been mentioned in various references [8]. Probability that the parameter of ground movement Y exceeds a specific value in the event of a definite earthquake in a definite site will be equal to:

and magnitude (M) are often used to estimate the random parameter. Therefore the above relationship will be converted to the following equation:

probability density functions of magnitude and distance which should be determined for

each seismic source with respect to the source properties and its distance to the site. Now, if it is assumed that N seismic sources,

$$\lambda_y = \sum_{i=1}^N v_i \iint P[Y > y | m, r] f_{M_i}(m) f_{R_i}(r) dm dr$$

The obtained  $\lambda_y$  parameter can also be interpreted as the annual occurrence probability of y. In case of the existence of a

$$R = 1 - e^{-\lambda_y T}$$

The value of R is also called the earthquake occurrence risk. In this study, two different risk values of 10% in 50 years (corresponding to return period of 475 years) and 2% in 50 years (corresponding to return period of 2475 years) have been used.

**3- Peak ground acceleration maps**

Although peak ground movement parameters like peak ground acceleration don't apply in uniform hazard spectra unlike scaled spectra, presenting the parameter to make a comparison with previous studies can be useful. Using the four selected attenuation relationships, peak ground acceleration maps have been produced for the horizontal component and the two mentioned probabilities for the region of Khuzestan province. The maps were obtained through dividing Khuzestan province region into a grid of 0.05°×0.05° points and making calculations of seismic hazard analysis for all the points. The

each of which with a seismic activity rate of  $v_i$ , can affect the site, the total probability of Y exceeding the value y will be equal to:

$$\dots\dots\dots (9)$$

Poison distribution for the time distribution of earthquakes, the occurrence probability of exceeding y value in T years will be equal to

$$\dots\dots\dots (10)$$

method of presenting the results in these maps is through zoning the maps into several iso acceleration zones. In the figures (3-a), (3-b), (3-c) and (3-d), maps of peak horizontal ground acceleration for the region of Khuzestan province have been drawn with a probability of 10% in 50 years using the four attenuation relationships.

**Spectral acceleration maps**

Doing seismic hazard analysis calculations for a collection of points 0.05° apart in the region of Khuzestan province and using the four spectral attenuation relationships in the calculations, it is possible to draw the spectral acceleration maps. In this study, the spectral acceleration maps have been produced in four periods of 0.20, 0.50, 1.00 and 2.00 s with the two probabilities of 2% and 10% during 50 years and with the assumption of bed rock site conditions for the region of Khuzestan province. In figure 4, the spectral acceleration maps in a 0.2 s period and for the probability of 10% in 50 years have been drawn for the region of

Khuzestan province. Using the maps and calculation of the spectral acceleration in all points, it will possible to reach the average value of the spectral acceleration in the region of Khuzestan province and use them to draw average uniform hazard spectra. For this important purpose, using the maps and all the four attenuation relationships, the average values of the spectral acceleration in five different periods (zero period or PGA and four periods of 0.20, 0.50, 1.00 and 2.00) with the two mentioned probabilities were obtained for the region of Khuzestan

province with the assumption of rock site conditions and the results are shown in table 1.

**Average uniform hazard spectra for the region of Khuzestan province**

Using the existing information of table 1, it is possible to draw easily the average uniform hazard spectra for the region of Khuzestan province, which has been carried out in figure 5 for the two probabilities of 2% and 10% during 50 years.

**Table 1: Average values of peak horizontal ground acceleration and horizontal spectral accelerations (5% damping)**

	Occurrence Probability of 10%/50				Occurrence Probability of 2%/50			
	Spectral attenuation relationships				Spectral attenuation relationships			
	ASB (1996)	Zare (1999)	Khade mi (2002)	Zare and Sabzali (2006)	ASB (1996)	Zare (1999)	Khademi (2002)	Zare and Sabzali (2006)
PGA	0.180 g	0.263 g	0.494 g	0.385 g	0.300 g	0.495 g	0.876 g	0.574 g
Sa (0.20)	0.448 g	0.930 g	0.747 g	2.233 g	0.777 g	1.928 g	1.353 g	4.081 g
Sa (0.50)	0.396 g	0.684 g	0.695 g	1.534 g	0.762 g	1.464 g	1.338 g	2.834 g
Sa (1.00)	0.207 g	0.323 g	0.187 g	0.572 g	0.399 g	0.665 g	0.275 g	1.048 g
Sa (2.00)	0.126 g	0.113 g	0.095 g	0.280 g	0.233 g	0.218 g	0.131 g	0.517 g

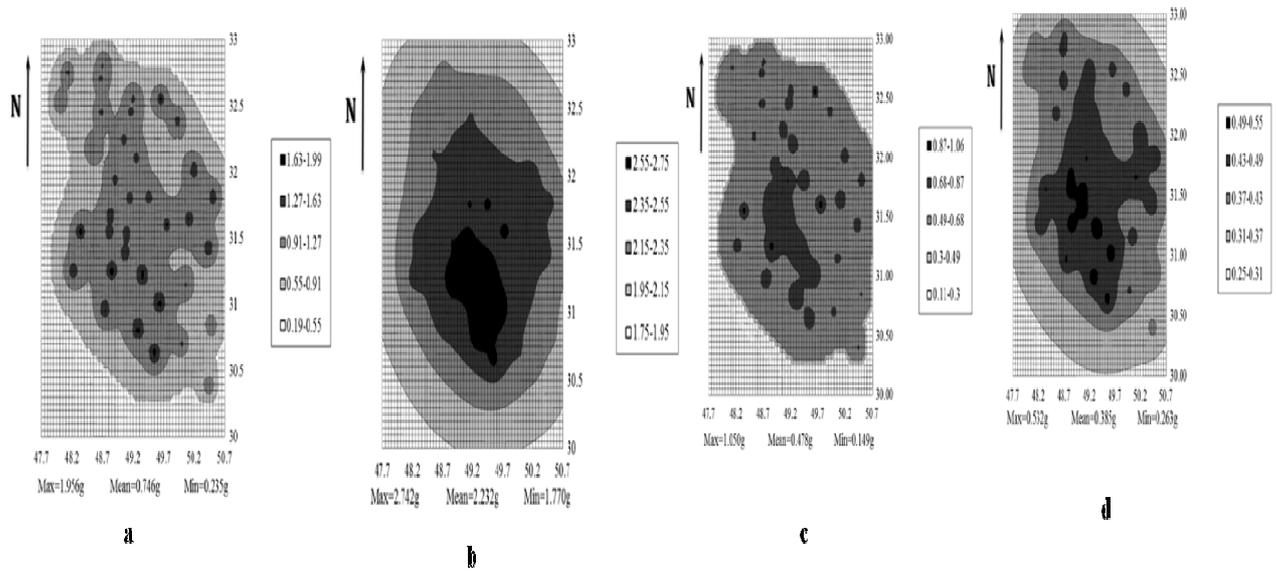


Figure 3: Map of peak horizontal ground acceleration (g), 10% probability in 50 years, rock site for the region of Khuzestan province using spectral attenuation relations a)Ambraseys, Simpson & Bommer (1996) b) Zare (1999) c) Khademi (2002) d) Zare and Sabzali (2006)

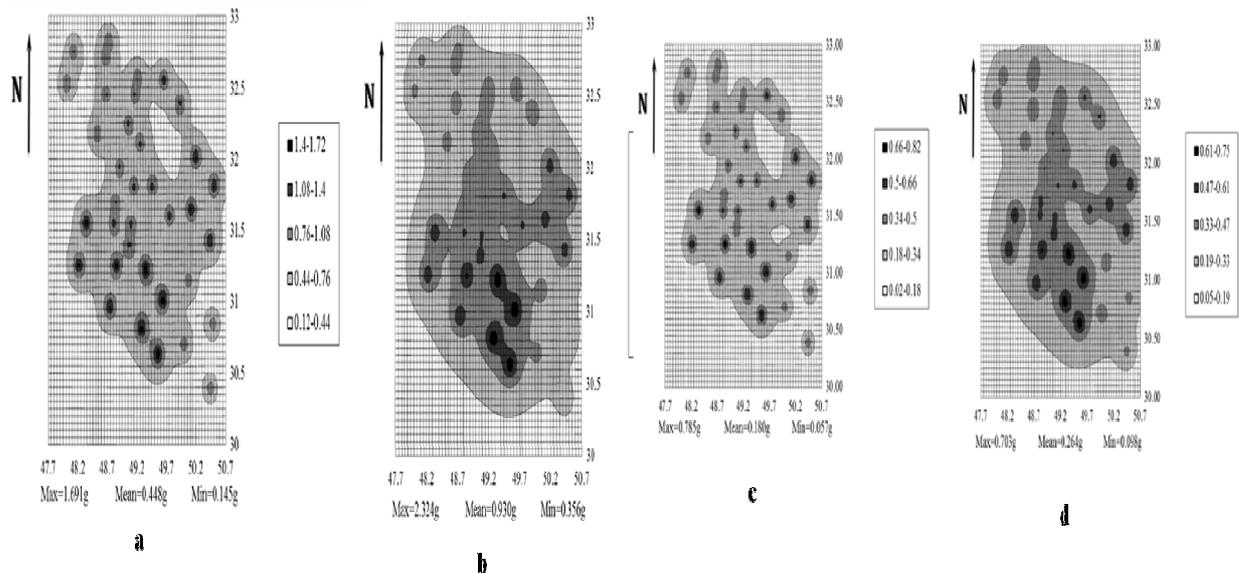


Figure 4: Map of horizontal ground acceleration of 0.2 s (g), 10% probability in 50 years, rock site for the region of Khuzestan province using spectral attenuation relations a)Ambraseys, Simpson & Bommer (1996) b) Zare (1999) c) Khademi (2002) d) Zare and Sabzali (2006)

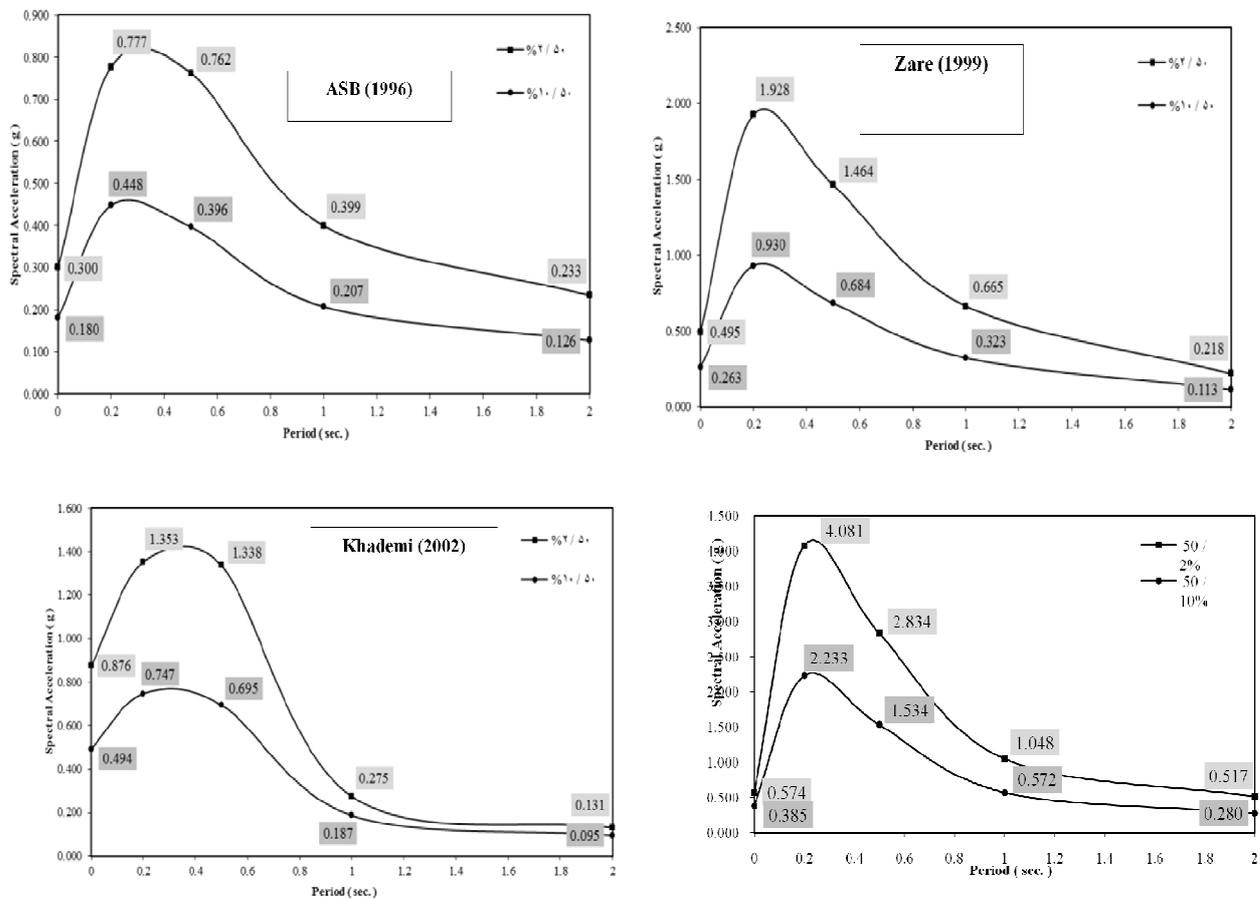


Figure 5: Average uniform hazard spectra for the region of Khuzestan province, rock site, probability of 2% and 10% in 50 years

## SUMMARY AND CONCLUSION

In order to perform probabilistic seismic hazard analysis for the region of Khuzestan province, having defined the region, an area surrounding it was selected as the project area. Selection of the area was such that all the seismic components and factors which may affect the region of Khuzestan province were present. Having defined seismic sources and estimating seismic parameters necessary for probabilistic seismic hazard analysis of each of the sources, it was made possible to

evaluate the seismic hazard of the region of Khuzestan province. The results obtained from seismic hazard assessment of the region of Khuzestan province which included the horizontal component of peak ground acceleration, spectral accelerations in four different periods and horizontal components of average uniform hazard spectra with two probabilities of 10% and 2% during 50 years, the spectral attenuation relationships used to evaluate them were presented separately. The results obtained from application of the four

different spectral attenuation relationships in the project indicate that the best alternative for assessment of seismic hazard in a region is to use relations that are determined only by the information registered in their region. In addition, in view of the investigation of the effect of the spectral attenuation relations on the results obtained from probabilistic seismic hazard analysis in this study, one of the factors which can be stated as dependent on the spectral attenuation relationships is the spectral magnitude of uniform hazard spectra in all periods. In the end, in order to achieve the defined final objective of the study, the situation of earthquake hazard in various regions of Khuzestan province is different and in general, it is more in northern and central regions than other areas.

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