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**INVESTIGATION OF THE IMPACT OF SPECTRAL ATTENUATION
RELATIONSHIPS ON OUTCOMES RESULTED FROM THE PROBABILISTIC
SEISMIC HAZARD ANALYSIS**

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ABSTRACT

Having a proper estimation from the amount of earthquake forces is a prerequisite for a safe design and seismic retrofitting of the structure, which due to the random nature of earthquake phenomenon, estimation like this should be done in a probabilistic framework called probabilistic seismic hazard analysis. In the analysis of seismic hazard, attenuation relationships are known as a key component. An attenuation relationship is a mathematical equation which estimates the parameters of the earth's motion in form of the functions of earthquake magnitude, distance, site condition and probably other parameters. Spectral attenuation relationships which in fact are the new generation of attenuation relationships, estimate a spectral parameter instead of estimating parameters related to ground movements. Selecting a proper attenuation relationship for using in seismic hazard analysis of seismic designs is very important because the result of the seismic hazard analysis can be dramatically affected by it. Certainly, the best attenuation relationship for being used in a certain area is a relationship which is provided by using information available in the same area. Khuzestan province is the specific area considered in this article. A large part of the country's infrastructure such as refineries, oil facilities as well as very large dams and some historical cities are placed in this province with a high relative seismic risk which is the main reasons for choosing Khuzestan province as the target range.

Determination of the uniform hazard spectra is one of the results of applying the spectral attenuation relationships in calculations related to seismic hazard analysis. Uniform hazard spectrum is a response spectrum which a same possibility of occurrence is dominant in all points of its range in different time periods.

According to the fundamental role of spectral attenuation relationships in seismic hazard analysis, in this paper, it has been tried to conduct a comparison in terms of the impact of spectral attenuation relationships on the shape and the amounts of the horizontal uniform hazard spectra amplitude in three types (maximum, mean and minimum) at periodic times and different possibilities of occurrence by applying four different spectral attenuation relationships in the calculations of probabilistic seismic hazard analysis. Obtained results show that the difference between mentioned spectra will be more visible (low return period) in above probabilities of occurrence. Also, by changing the spectral attenuation relationships used in the calculation of hazard analysis, the shape and the amounts of the horizontal uniform hazard spectral amplitude will change which reflects the importance of choosing a suitable attenuation model for seismic hazard analysis.

Keywords: Earthquake, spectral attenuation relationships, probabilistic seismic hazard analysis, Khuzestan province

INTRODUCTION

Nowadays, by observing calamities and irreparable disasters which already happened by different earthquakes in Iran and caused unbelievable loss of life and property, there is no doubt in the importance of dealing with earthquake theorem and its dangers. This is an undeniable fact that Iran is located in an area with a very high level of seismic risk and there is always the risk of another major earthquake. Another fact that should be accepted is that, with human's present knowledge, it does not seem to have another way to deal with this natural phenomenon

except designing earthquake-resistant structures and retrofitting existing structures. Undoubtedly, the first step for this aim is nothing but analyzing and evaluating the risks of earthquakes and obtaining a good estimation from earthquake's forces. In other words, all these facts demonstrate the importance of researches in which deals with analyzing and evaluating the risk of earthquake and naturally this article will also be among the same researches. But, in some cases, the importance of the selected target domain in this research is why

the necessity of doing such investigations is doubled. Without any doubt, Khuzestan province is considered as the beating heart of Iran's economy and the vital artery for its industry. A large part of the country's infrastructure such as refineries, oil and petrochemical facilities as well as large dams are placed in this province that sometimes have been constructed in high seismic zones and more than anything, proves the need for discussing the risks of earthquakes in this province. Also, according to the archaism of this province and the location of some of its historic towns in areas with high relative seismic risk, it's necessary to evaluate the hazards caused by earthquake in these regions with acceptable accuracy.

The complexity of natural phenomena in general and a phenomenon such as earthquake, in particular, is the reason of why it's not possible to control these kinds of phenomena with current knowledge and precisely determine the position and magnitude of future earthquakes. In such cases, the use of the science of statistics and possibilities is probably the only possible and practical option in analyzing these phenomena. The method of Probabilistic Seismic Hazard Analysis is created from combining the concepts of possibilities with the Seismic Geotechnical Science which is

known as the most common, most complete and best method to estimate the seismic hazard. By using this method, it will be possible to consider the available uncertainties of various parameters and to properly apply the changes of earthquake's location and magnitude into the calculations. The purpose of the probabilistic seismic hazard analysis is to reasonably estimate the risk of parameters related to ground motion in a certain site [1].

The method of probabilistic seismic hazard analysis needs an attenuation relationship in order to model the earthquake source, wave propagation path between sources and the site and also the geological conditions under the site, by using simple parameters. In analyzing seismic hazard, attenuation relationships are considered as key components. An attenuation relationship is a mathematical equation which estimates the parameters of the earth's motion in form of the functions of earthquake magnitude, distance, site condition and probably other parameters. Since the parameters related to the ground motion are the same parameters used by design engineers in the seismic design of structures, the importance of these relationships will be well known. These relationships are provided generally through statistical analysis on the recorded

information of occurred earthquakes [2]. Spectral attenuation relationships which in fact are the new generation of estimated attenuation relationships, will estimate a spectral parameter instead of estimating parameters related to the ground motion. Due to abundant applications of pseudo-spectral acceleration in determining seismic forces, spectral acceleration attenuation relationships have the largest share between these relationships. The analysis results of seismic hazard are highly dependent on the attenuation relationship used in the calculation, so, in selecting an appropriate attenuation relationship, adequate attention should be given. The use of suitable attenuation models is required for the considered range in order to perform the investigations of seismic hazard analysis correctly and to find the ground motion parameters for structures' seismic design and development projects [3].

The determination of Uniform Hazard Spectrum (UHS in summary) is one of the results of applying the spectral attenuation relationships in calculations related to seismic hazard analysis. Uniform hazard spectrum is a response spectrum which the same possibility of occurrence is dominant in all points of its domain in different time periods. In other words, the uniform hazard

spectrum is made up of a series of separate points that all of these points are calculated for the same probability of occurrence [3].

With such an introduction, the framework of the present article can be defined. In this article, it has been tried to evaluate the impact of spectral attenuation relationships on the obtained results of probabilistic seismic hazard analysis for seismic areas of Khuzestan province by using the comparison of uniform hazard spectra in three modes of maximum, mean and minimum. In this study, the procedure used to produce uniform hazard spectra is based on the known methods of probabilistic seismic hazard assessment. The requisites of using such methods, on the one hand is to identify the status of seismotectonics and determine and define the existed seismic source in the range of the project and on the other hand, choosing suitable attenuation relationships for acceptable estimation of desired parameters. Then, by conducting necessary calculations for assessing the seismic hazard in different time periods and determining the amounts of spectral range for a specified probability of occurrence, uniform hazard spectrum can be drawn for a certain point.

2. Definition of the target range, plot area and the status of seismotectonics

Seismic zones of Khuzestan province are the target range of this research. On this basis, the longitude: 47.70° to 50.70° and latitude of 30.00° to 33.00° is defined as the target range. In order to analyze the seismic risk in this range, a very wide plot area is considered with the longitude of 47.00° to 51.00° and latitude of 30.00° to 34.00° and all seismic factors (i.e. available faults that may somehow affect the target range) are detected in that area (Figure 1). To obtain a correct attitude of the seismic status of the range of Khuzestan province, this area is divided into a network of points with intervals of 0.05 degree and the calculations of probabilistic seismic hazard analysis have been performed for all points of this network.

According to conducted research, some of the faults located in the desired plot area are detected very well, but there is a little detailed information about some other faults. Mountain Front Fault (the boundary of Folded Zagros with piedmonts and coastal plain of Persian Gulf which is made of many faults with the length of 15 to 115 km and in fact, the seismic faults of Behbahan, Teshan, Indica and Balarood are some parts of it), Dezful Embayment Fault (the northern boundary of Dezful Embayment which is placed between the mountain front fault and the South of Zagros and Lahbari, Dezful and

Rāmhormoz faults form different parts of this fault), Ahvaz Fault (with the approximate length of 60 kilometers in the south of the Khuzestan province which probably was the reason of the historical and devastating earthquake at 218 AH), Aghajari fault (with an approximate length 150 km), The Maroon fault (with an approximate length 50 km) are among the most important detected faults in the plot area. Also, in this figure, the centers of earthquakes which occurred in this area are displayed along with the target range and also the positions of existed towns.

Such a plan can be a good basis for defining and modeling the seismic sources in this range. Based on this map and in a general judgment and with regard to 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 the Khuzestan province is high. In any case, seismic devices gathered from reliable sources [4] were combined with historical earthquakes [5] to perform the calculations of seismic hazard analysis, and after conducting necessary corrections such as removing the pre-aftershocks with using the method of spatial-temporal windows [6], the unification of magnitudes and determining the completeness of the catalog and etc., the final catalog of the earthquake was prepared and

with using this catalog, seismic parameters such as the rate of seismic activity, seismic coefficient and the maximum

seismic potential were calculated for faults modeled as a linear geometry.

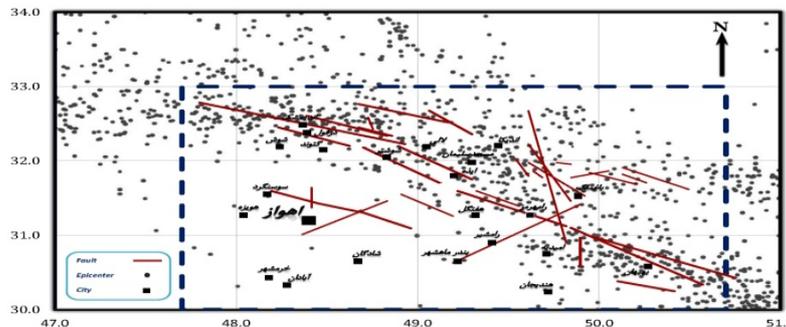


Figure 1- The definition of target range of plot area, identifying the existed main faults in this range and showing the center of earthquakes occurred in this area

3. Selecting appropriate spectral attenuation relationships for probabilistic analysis of seismic hazard in the range of Khuzestan Province

Attenuation relationship is a mathematical relationship which describes a ground motion parameter based on various parameters such as magnitude, distance, site condition and probably other parameters. The overall shape of an attenuation relationship can be as follows:

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

In which Y, is the desired parameter of ground motion. The difference between spectral attenuation relations with attenuation relationships is that the spectral attenuation relationship describes a spectral parameter such as spectral acceleration instead of describing ground motion parameters. Therefore, these relationships can be used directly in creating spectrum.

To assess seismic hazards, choosing a suitable spectral attenuation relationship is very important. The most important factor in choosing a spectral attenuation relationship for an area is to consider the Seismotectonic conditions of that area. Therefore, a suitable relation for an area is a relation which is created based on the use of information recorded in the same area. According to this general condition, in this research, four valid spectral attenuation relationships have been used for seismic hazard analysis in the range of Khuzestan province. Three of these four relationships have been produced only with the use of information recorded in Iran, and in the first relationship, although, in addition to the use of data recorded in Iran, existing information in other countries have also been used, but due to the high volume of information related to Iran, according to its producers, this relationship will be also valid

for Iran. These four spectral attenuation relationships include:

1. Spectral attenuation relationship proposed by Ambraseys, Simpson & Bommer (1996)
2. Spectral attenuation relationship proposed by Zareh (1999)

$$\text{Log}(y) = C_1 + C_2.M + C_4.\text{Log}(\sqrt{d^2 + h_0^2}) + C_A.S_A + C_S.S_S + \sigma.P \quad (2)$$

In which y is the desired parameter to estimate the spectral acceleration or PGA in terms of g , M is the magnitude of earthquake on the scale of surface waves and d represents the closest distance of the station to the surface faulting, the causative fault of earthquake in terms of kilometer. Also, H_0 is a constant value that is determined based on the coefficients C_1 , C_2 and C_4 and should be calculated separately for different periods of time. The standard deviation of $\text{Log}(y)$ is shown with σ that the fixed amount of P , when mean values be desired, is equal to zero and if the mean plus one standard deviation-

$$\log(Sa(T)) = a(T).M + b(T).R - \log(R) + C_i.S_i + \sigma.P \quad (3)$$

In which the coefficients of this equation have been provided in the form of a coefficient, b coefficient, four coefficients of C and the standard deviation σ for different periods of time. In this equation, M is the earthquake moment magnitude and R is the distance from the epicenter of the earthquake.

3. Spectral attenuation relationship proposed by Khademi (2002)

4. Spectral attenuation relationship proposed by Zareh and Sabzali (2006)

The first relationship was suggested by Ambraseys and colleagues in 1996 as follows [7]:

which corresponds to 84.1% - be desired, fixed amount of P will be equal to one. Two parameters of S_A and S_S along with coefficients of C_A and C_S are used to control the site conditions. If two parameters of S_A and S_S be equal to zero, the resulted relationship will be related to the rock site conditions. If S_A equals one and S_S equals zero, the harsh soil site conditions is dominant and if S_A equals zero and S_S equals one, the attenuation relationship related to the soft soil site conditions will be achieved.

The second relationship was proposed by doctor Zareh in 1999 as follows [7]:

Also, by the use of P -value, the average or above average mode could be defined and by using S parameters, different site conditions will be described which in this study, the rock site conditions is desired.

The third relationship was offered by Mr. khademi in 2002 as follows [7]:

$$Y = C_1 \cdot \exp(C_2 \cdot M) (R + C_3 \cdot \exp(C_4 \cdot M))^{C_5} + C_6 \cdot S \quad (4)$$

In which Y is the desired parameter (ground acceleration or spectral acceleration in terms of g), M is the magnitude and R is the distance to the fault in terms of kilometers. The magnitude used in this relationship is made of the moment magnitude. S parameter is a zero-one variable that always controls the site conditions. If S is equal to zero, the rock

site condition is dominant and if this parameter equals one, the soil site conditions will be established which in this study, the rock site conditions is desired. The amounts of coefficients C1 to C6 have been calculated for various time periods.

The last relation was suggested by Dr.Zareh and Sabzali in 2006 as follows [7]:

$$\text{Log}(Sa(T)) = a_1(T) \cdot M + a_2(T) \cdot M^2 + b(T) \cdot \text{Log}(X) + C_i(T) \cdot S_i + \sigma(T) \cdot P \quad (5)$$

In which $S_a(T)$ is the spectral acceleration in the time period of T which is in terms of g. M, the magnitude used in this relationship is made of the moment magnitude and the distance (X) defined for this model, considers the distance from the epicenter. The coefficients of $\{a_1(T), a_2(T)\}$ and $b(T)$ which respectively represent the magnitude coefficient and the non-elastic attenuation coefficient, are periodic time-dependent parameters that are defined for different periods of time. Also, $\sigma(T)$ is defined as the number of standard deviation of logarithmic spectral acceleration at time period of T. It is evident that in case of providing the amount of zero for P-value, the relationship would be in the average and with providing the amount of one, the above-average mode – corresponding with the occurrence

probability 84.1% - would be dominant. The values of $C_i(T)S_i$ control various site conditions in the attenuation relationship. This relationship has the ability to model four different site conditions which by putting the amounts of zero or one for S_i parameters, desired site conditions would be applied.

4. The calculations of probabilistic seismic hazard analysis

The method used for estimating the seismic hazard of a site is determined from a known rule in probabilistic science that is mentioned in various references [8]. The probability of exceeding the ground motion parameter (Y) from its specified amount, due to a specific earthquake, in a specified site, will be equal to:

$$P[Y > y] = P[Y > y | X]P[X] = \int P[Y > y | X]f_x[X]dx \quad (6)$$

In which X represents a vector which includes all the effective random variables in Y and also f_X is a function made of the probability density function that shows the existing uncertainty in random variables. In

$$P[Y > y] = \iint P[Y > y | m, r] f_M(m) f_R(r) dm dr \tag{7}$$

In which $P[Y > y | m, r]$ is the same attenuation relationship and $f_M(m)$ and $f_R(r)$ are the probability density function for the magnitude and source-site distance that should separately be determined for each seismic source according to the specifications of the source and its distance

$$\lambda_y = \sum_{i=1}^N v_i \iint P[Y > y | m, r] f_{M_i}(m) f_{R_i}(r) dm dr \tag{8}$$

The obtained value for λ_y parameter can also be interpreted as the annual occurrence likelihood of y . With the assumption of a Poisson distribution for the temporal distribution of earthquakes, the probability of exceeding the value of y during T years will be equal to:

$$R = 1 - e^{-\lambda_y T} \tag{9}$$

R-value is also known as the earthquake risk. In this study, two different risks were used for determining the uniform hazard spectra, the 10% possibility during 50 years (corresponding with a return period of 475 years) and 2% during 50 years

most cases, two variables are used in estimating the random parameter, which are the distance (R) and magnitude (M). Therefore, the above relationship will be like this:

from the site. Now, if it is assumed that N number of seismic sources, each with seismic activity rate of v_i , be able to affect the site, then the overall likelihood of exceeding Y from the amount of y will be equal to:

(corresponding with a return period of 2475 years).

5. The impact of four introduced spectral attenuation relationships on the shape and amounts of the horizontal uniform hazard spectral amplitude

In this section of the article, horizontal uniform hazard spectra were plotted in three modes (maximum, average and minimum) that were obtained from using the four spectral attenuation relationships which were introduced in the calculations of probabilistic seismic hazard analysis for two probabilities of 2% and 10% during 50 years for Khuzestan province.

The maximum, average and minimum values of the peak ground acceleration and horizontal spectral accelerations for a 2% probability of occurring in 50 years were respectively presented in tables (1), (3) and (5) and also, the mentioned amounts with 10% probability of occurring in 50 years were presented in tables (2), (4) and (6) at five different periods of time, 5% damping and with the stone site condition which were calculated by using four different spectral

attenuation relationships for Khuzestan province. By using the information of mentioned tables, horizontal uniform hazard spectra have been displayed in five different time periods (zero-period which is the same PGA and four periods of 0.20, 0.50, 1.00, 2.00 seconds) and in three cases (maximum, average and minimum) for a 2% probability in 50 years, respectively, in figures (2a), (3a) and (4a) and for a 10% probability in 50 years, in figures (2b), (3b) and (4b).

Table 1- Maximum values of peak ground acceleration and horizontal spectral acceleration in the plot area, with 2% possibility of occurring in 50 years

Spectral attenuation relationship	PGA	Sa (0.20)	Sa (0.50)	Sa (1.00)	Sa (2.00)
Ambraseys, Simpson & Bommer (1996)	1.451g	3.275g	3.631g	1.535g	0.958g
Zareh (1999)	1.554g	4.996g	4.023g	1.649g	0.496g
Khademi (2002)	1.836g	4.014g	3.658g	0.972g	0.501g
Zareh and Sabzali (2006)	1.843g	4.993g	3.678g	1.416g	0.751g

Table2- Maximum values of peak ground acceleration and horizontal spectral acceleration in the plot area, with 10 % possibility of occurring in 50 years

Spectral attenuation relationship	PGA	Sa (0.20)	Sa (0.50)	Sa (1.00)	Sa (2.00)
Ambraseys, Simpson & Bommer (1996)	0.785g	1.691g	1.553g	0.636g	0.392g
Zareh (1999)	0.703g	2.324g	1.465g	0.616g	0.194g
Khademi (2002)	1.050g	1.956g	1.818g	0.455g	0.213g
Zareh and Sabzali (2006)	0.532g	2.742g	1.928g	0.739g	0.381g

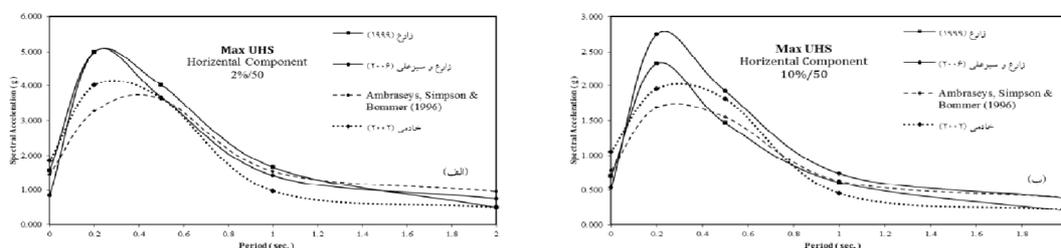


Figure 2 Maximum horizontal uniform hazard spectra established for Khuzestan province, with the bedrock site condition, 5% damping

A) - With 2% possibility of occurring in 50 years B) - With 10% possibility of occurring in 50 years

Table 3- the average values of peak ground acceleration and horizontal spectral acceleration in the plot area, with 2% possibility of occurring in 50 years

Spectral attenuation relationship	PGA	Sa (0.20)	Sa (0.50)	Sa (1.00)	Sa (2.00)
Ambraseys, Simpson & Bommer (1996)	0.300g	0.777g	1.762g	0.399g	0.233g
Zareh (1999)	0.495g	1.928g	1.464g	0.665g	0.218g
Khademi (2002)	0.876g	1.353g	1.338g	0.275g	0.131g
Zareh and Sabzali (2006)	0.574g	4.081g	2.834g	1.048g	0.517g

Table4- Average values of peak ground acceleration and horizontal spectral acceleration in the plot area, with 10% possibility of occurring in 50 years

Spectral attenuation relationship	PGA	Sa (0.20)	Sa (0.50)	Sa (1.00)	Sa (2.00)
Ambraseys, Simpson & Bommer (1996)	0.180g	0.448g	0.396g	0.207g	0.126g
Zareh (1999)	0.263g	0.930g	0.684g	0.323g	0.113g
Khademi (2002)	0.494g	0.747g	0.695g	0.187g	0.095g
Zareh and Sabzali (2006)	0.385g	2.233g	1.534g	0.572g	0.280g

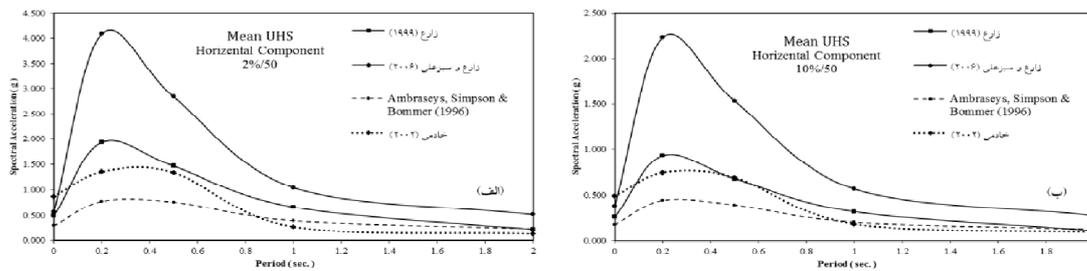


Figure 3 Average horizontal uniform hazard spectra established for Khuzestan province, with the bedrock site condition, 5% damping

A) - With 2% possibility of occurring in 50 years B) - With 10% possibility of occurring in 50 years

Table 5- Minimum values of peak ground acceleration and horizontal spectral acceleration in the plot area, with 2% possibility of occurring in 50 years

Spectral attenuation relationship	PGA	Sa (0.20)	Sa (0.50)	Sa (1.00)	Sa (2.00)
Ambraseys, Simpson & Bommer (1996)	0.094g	0.219g	0.242g	0.144g	0.097g
Zareh (1999)	0.159g	0.655g	0.735g	0.441g	0.173g
Khademi (2002)	0.191g	0.339g	0.315g	0.149g	0.095g
Zareh and Sabzali (2006)	0.381g	3.216g	2.180g	0.788g	0.372g

Table 6- Minimum values of peak ground acceleration and horizontal spectral acceleration in the plot area, with 10% possibility of occurring in 50 years

Spectral attenuation relationship	PGA	Sa (0.20)	Sa (0.50)	Sa (1.00)	Sa (2.00)
Ambraseys, Simpson & Bommer (1996)	0.057g	0.145g	0.146g	0.092g	0.058g
Zareh (1999)	0.098g	0.356g	0.381g	0.233g	0.096g
Khademi (2002)	0.149g	0.235g	0.233g	0.138g	0.072g
Zareh and Sabzali (2006)	0.263g	1.770g	1.192g	0.436g	0.204g

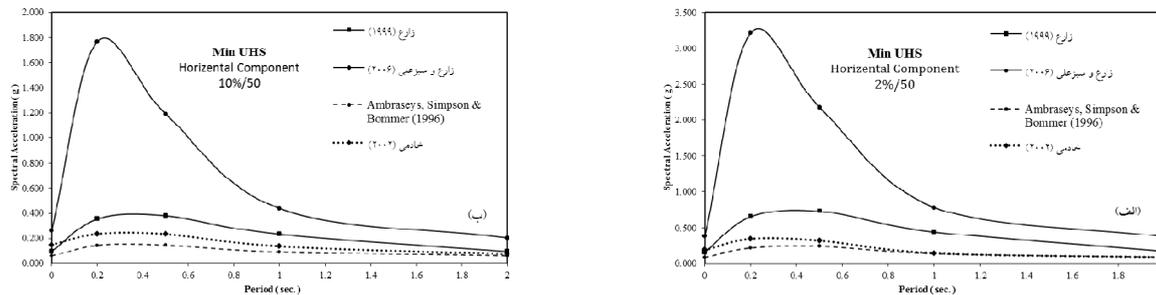


Figure 4- Minimum horizontal uniform hazard spectra established for Khuzestan province, with the bedrock site condition, 5% damping

A) - With 2% possibility of occurring in 50 years
 In a general comparison about the uniform hazard spectra it can be said that spectra which were specified by the use of four attenuation relationships introduced in this research, are similar with each other in some aspects. In each of the four spectral attenuation relationships, uniform hazard spectra have an upward trend in three modes (maximum, average and minimum) from the horizontal spectral acceleration value at the time of zero and will reach to the maximum spectral amplitude in a short time (maximum values of peak ground acceleration are nearly the same in all the relationships, except the attenuation relationship of Zareh and Sabzali (2006), which its peak ground acceleration is a bit more). In all spectra, the maximum amount of spectral amplitude for horizontal spectral acceleration occurs around the time period of 0.20 seconds, also, the maximum amount of spectral amplitude resulted by three spectral attenuation relationships, Zareh (1999), Khademi (2002), Ambraseys et al

B) - With 10% possibility of occurring in 50 years
 (1996), do not differ from each other so much. But the maximum values of spectral amplitude related to the spectral attenuation relationship of Zareh and Sabzali (2006) is much more than other relationships, and applying the information of near-field records in creating the spectral attenuation relationship of Zareh and Sabzali (2006) is the reason for such high levels of results. Another point about the obtained spectra from the spectral attenuation relationships of Zareh and Sabzali (2006) is the deference between uniform hazard spectra of Zareh and Sabzali (2006) with other spectra which by a reduction in the risk level shows a more significant gap in three modes (maximum, average and minimum). Also, the uniform hazard spectra resulted from the spectral attenuation relationship of Ambraseys et.al (1996), has a good posh (appropriate display for average), because the seismic records of more than 150 earthquakes in different countries have been applied in making this

relationship. Another thing that can be expressed about the uniform hazard spectra is the difference between spectra which is more visible in high probabilities of occurrence (for low-return period).

CONCLUSION

In this study, the average uniform hazard spectra for the stone site condition were determined with two possibilities of occurring (2% and 10%) in 50 years for the range of Khuzestan province by using the methods of probabilistic seismic hazard analysis. The first point that can be quite perceptible is the changing shape of these spectra in the entire uniform hazard spectra obtained for various cities, which reshapes by the changes in spectral attenuation relations. In fact, fully unlike the form of scaled spectra which are always constant, the form of uniform hazard spectra will change based on parameters such as earthquake's magnitude, distance-to-fault and the probability of occurrence or generally, the spectral attenuation relationships and that is because of the attenuation relationship which is a mathematical equation that estimates the parameters of the earth's motion in form of the functions of earthquake's magnitude, distance, site condition and probably other parameters. With regard to the importance of the uniform hazard spectra in terms of their

ability to homogenize the level of safety for all existing structures in the range, therefore, selecting a suitable attenuation relationship is very important to be used in seismic hazard analysis for seismic designs and ultimately, to create uniform hazard spectra, because the result of the seismic hazard analysis will dramatically be impressed by that. Definitely, the best attenuation relationship to use in a specific area is the relationship that is prepared based on the information in the same area.

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