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SEISMIC HAZARD ANALYSIS AND DEVELOPING THE UNIFORM HAZARD SPECTRA FOR VULNERABILITY ANALYSIS OF AN EXISTING BUILDING

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SUMMARY

A site investigation as well as a Seismic Hazard Analysis (SHA) have been carried out for an important existing building in north of Tehran (capital of Iran). The aim has been estimating the level of seismic hazard for the building and developing the Uniform Hazard Spectra (UHS) for horizontal as well as vertical component to verify the performed seismic design of the building. At first, it was tried to recognize all the active faults around the building. Secondly, by using the appropriate attenuation laws, the PGA values on the site were estimated. These values obtained for the site vary between 0.112g and 0.569g for 10% probability of exceedence in 50 years ground motions depending on the applied attenuation laws. Finally, the UHS, which are more reliable for design purposes, were constructed for the 2% and 10% probability of exceedence in 50 years ground motions.

INTRODUCTION

As Tehran is located in the high seismic area, reduction of seismic risk in different parts of this great city by controlling the behavior of structures, particularly the key buildings is necessary. The best way for performing a reliable seismic hazard analysis is using both deterministic and probabilistic methods. A study of this kind has been recently performed by the authors for a railway bridge [1]. This paper reports another actual case of applying these methodologies for an existing 8-story international research center building. At first, it was tried to recognize all the seismic sources (faults) in a radius of 110 km around the building, and to evaluate their seismic potential based on the seismic activities in recent centuries.

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Secondly, by using the appropriate attenuation relationships, the PGA values on the site were estimated by considering the focal depths of recorded earthquakes, horizontal site-to-source distance and the local soil conditions. Then the PGA values were calculated by using deterministic method and hazard curves for the site were prepared by using probabilistic method. Finally, the UHS for horizontal as well as vertical component were constructed for the 2% and 10% probability of exceedence in 50 years ground motions based on spectral acceleration curves.

SITE LOCATION AND SEISMIC SOURCES PARAMETERS

The studied site in this paper corresponds to an important building in the north of Tehran (51.47^0 T and 35.80^0 L). This building is located in a distance of about 2 km from North Tehran fault. Some important faults around the site in an area with radius of about 110 km are Mosha, North Alborz and Kandovan. By using Iran Earthquake Catalogue all of the ground motions with magnitude of more than 4.0, which were related to nearest linear faults (i.e. North Tehran, Mosha, North Alborz and Kandovan), or area fault, including active faults in south-east of Tehran were considered for hazard analysis. Faults and site location are shown in Figure 1 and earthquake data are shown in Table 1.

Figure 1- Faults and site location

Table 1- Earthquake data for the building site

Fault	Date	Longitude	Latitude	Depth	m_b
North Tehran	*0864*	*35.7*	*51*	---	*5.3*
	1988	*36.01*	*50.6*	*33*	*4.6*
Mosha	*1830*	*35.7*	*52.5*	---	*7.1*
	1930	*35.8*	*52.1*	---	*5.2*
	1935	*35.8*	*52.8*	---	*5.2*
	1957	*36*	*52*	---	*4.2*
	1973	*35.77*	*52.57*	*29*	*4.3*
	1983	*35.961*	*52.228*	*33*	*5.4*
	1985	*35.629*	*52.699*	*10*	*4.8*
	1988	*35.628*	*52.38*	*33*	*4.2*
	1994	*35.9*	*51.88*	*33*	*4.5*
	1997	*35.67*	*52.50*	*33*	*4*
	1997	*35.9*	*52.00*	*33*	*4*
North Alborz	*1687*	*36.3*	*52.6*	---	*6.5*
	1809	*36.3*	*52.5*	---	*6.5*
	1825	*36.1*	*52.6*	---	*6.7*
	1935	*36.2*	*53*	---	*5.5*
	1940	*36.4*	*52.1*	---	*5.5*
	1951	*36.1*	*52.5*	---	*4.5*
	1957	*36.21*	*52.72*	---	*6.5*
	1971	*36.2*	*52.7*	*27*	*5.2*
	1973	*36.59*	*51.19*	*40*	*4.7*
	1974	*36.2*	*52.8*	*68*	*4.5*
	1983	*36.797*	*50.789*	*42*	*4.8*
	1985	*36.608*	*51.911*	*33*	*4.3*
	1992	*36.3*	*52.65*	*33*	*5*
	1995	*36.56*	*51.20*	*33*	*4.1*
	1998	*36.6*	*51.6*	*33*	*4.2*
	1998	*36.47*	*52.17*	*33*	*4.8*
	2002	*36.34*	*51.99*	*33*	*4.3*
Kandovan	*1959*	*36.45*	*51.23*	*44*	*5.7*
	1966	*36.1*	*50.74*	*41*	*4.8*
	1970	*36.1*	*51.4*	*68*	*4.1*
	1993	*36.5*	*51.02*	*57*	*4.4*
	1998	*36.2*	*50.90*	*33*	*4.5*
Area source	*1868*	*34.9*	*52.5*	---	*6.4*
	1937	*34.8*	*52.1*	---	*5.5*
	1945	*34.8*	*52.1*	---	*4.7*
	1951	*34.8*	*52.1*	---	*5.0*
	1954	*35.3*	*52*	---	*4.5*
	1977	*34.886*	*52.059*	*26*	*5.4*
	1982	*35.208*	*52.355*	*33*	*4.6*
	1988	*35.28*	*52.35*	*10*	*5.0*
	1991	*35.44*	*52.32*	*33*	*4.5*
	1993	*35.21*	*52.15*	*60*	*4.6*
	1997	*35*	*51.80*	*33*	*4.7*
	2001	*34.62*	*52.23*	*64*	*4.2*

ATTENUATION RELATIONSHIPS

The general form of attenuation expression used in most investigation can be characterized by the expression:

$$y = b_1.f_1(M).f_2(R).f_3(M,R).f_4(P_i).\varepsilon \quad (1)$$

where y is the strong motion parameter to be predicted, b_1 is a constant and

$$f_1(M) = e^{b_2 M} \quad (1a)$$

$$f_2(R) = e^{b_4 R}\left[R + b_5\right]^{-b_3} \quad \text{or} \quad f_2(R) = e^{b_4 R}\left[\sqrt{R^2 + b_5^2}\right]^{-b_3} \quad (1b)$$

$$f_3(M,R) = \left[R + b_6 e^{b_7 M}\right]^{-b_3} \quad (1c)$$

$$f_4(P_i) = \sum e^{b_i P_i} \quad (1d)$$

In expressions (1a) to (1d) b_6 is a constant and M, R, b_2, b_3, b_4, b_5, b_7, P_i, and ε are respectively magnitude, site-to-source distance, magnitude attenuation rate, geometrical attenuation rate, the coefficient of elastic attenuation, the coefficient that limits the value of y at zero distance, negative coefficient that reduces the amount of magnitude scaling at short distances, site effect, random variable that is usually assumed to be log-normally distributed [2]. Although an attenuation relationship that includes all of the above factors is theoretically possible, two factors that are often represented in attenuation expressions are geometric spreading and magnitude.

In this study the following attenuation relationships have been used:

1) Boore, Joyner and Fummal [3]
2) Nuttli and Herrmann [4]
3) Battis [5]
4) Donovan and Bornstein [6]
5) Crouse [7]
6) Campbell and Bozorgnia [8]
7) Ambraseys 1995 [9]
8) Ambraseys&Bommer [10]
9) Zare and Ashtiany [11]

CALCULATING PGA BY DETERMINISTIC SEISMIC HAZARD ANALYSIS (DSHA) METHOD

For using this method, PGA values were obtained from designated attenuation relationships. The used site-to-source distance, *R* and the maximum moment magnitude of occurred earthquakes, M_{max} are presented in Table 2, and PGA values in Table 3. The maximum calculated PGA value is 1.75g, which is obtained by using Battis attenuation relationship.

Table 2- The values of *R* and M_{max} for all sources

Seismic Sources	North Tehran	Mosha	North Alborz	Kandovan	Area source
R (km)	2	13	69	35	71
M_{max}	5.3	7.1	6.7	5.7	6.4

Table 3- The PGA values obtained from various attenuation relationships

Seismic Faults					Attenuation Relationship
Area source	**Kandovan**	**North Alborz**	**Mosha**	**North Tehran**	
0.041	0.047	0.048	0.203	0.149	*Boore, Joyner and Fummal*
0.152	0.129	0.216	0.688	0.423	*Nuttli and Herrmann*
0.233	0.175	0.347	1.75	0.287	*Battis*
0.047	0.056	0.062	0.359	0.522	*Donovan and Bornstein*
0.159	0.193	0.213	0.759	0.71	*Crouse*
---	0.034	---	0.35	0.918	*Campbell and Bozorgnia**
0.056	0.056	0.068	0.17	0.059	*Ambraseys*
0.09	0.116	0.111	0.641	0.594	*Ambraseys&Bommer*
0.071	0.075	0.095	0.712	0.394	*Zare and Ashtiany*

*This Relationship is used only for distances at least 60 km far from a source

HAZARD ESTIMATION BY PROBABILISTIC SEISMIC HAZARD ANALYSIS (PSHA) METHOD

This method considers all earthquakes with possible magnitude, on all significant sources, at all possible distances from the site, considering the likelihood of each combination. Therefore, using PSHA allows a desired facility to be designed for ground motion with a specified probability of exceedence [12].

Steps Involved in a PSHA method:

In the first step, all seismic sources that can produce damaging ground motion at the site were identified. Then each line source was divided into 3, 4 or 5 segments depending on its length and geometry. Distances of centers of various segments to the site are given in Table 4.

Table 4- Distances between the centers of source segments to the building

		Site-to-Segment Distance (Km)				
Seismic Sources	**No. of Segments**	**1**	**2**	**3**	**4**	**5**
North Tehran	3	2	13	54	---	---
Mosha	5	18	26	53	60	97
North Alborz	4	69	80	104	119	---
Kandovan	3	38	52	74	---	---
Area source	4	71	104	107	132	---

The second step was the establishment of earthquake recurrence relationships, magnitude distribution and average occurrence rates which were obtained from equations (2) to (4).

$$\ln N = \alpha - \beta M \qquad \text{or} \qquad N(m) = e^{(\alpha - \beta M)} \tag{2}$$

$$\vartheta = N(m_o) - N(M_{\max}) \tag{3}$$

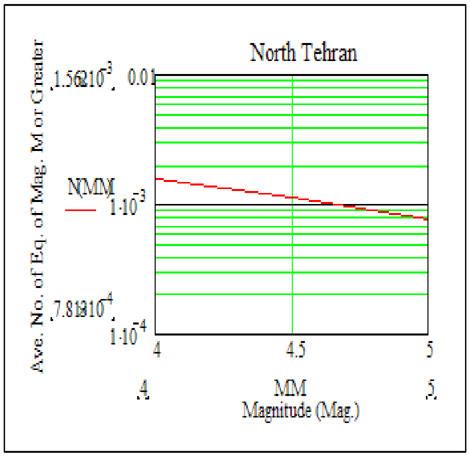
$$f(M) = C\beta e^{-\beta(M - m_o)} \tag{4}$$

where α and β are Gutenburg-Richter coefficients, N is the number of earthquakes with magnitude greater than or equal to m_0 (the lower magnitude limit, which was supposed to be 4.0), M is the magnitude, and C is as follows:

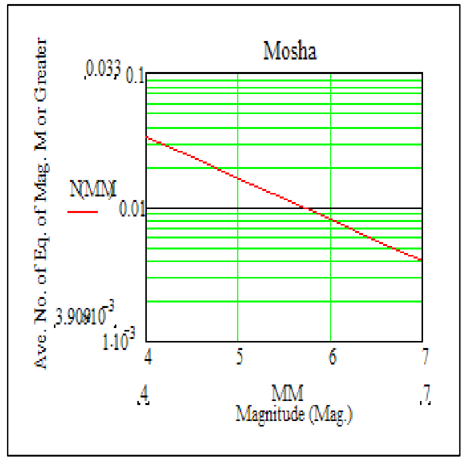
$$C = \frac{1}{1 - e^{-\beta(M_{\max} - m_o)}} \tag{5}$$

Figure 2 indicates Gutenburg-Richter relationship.

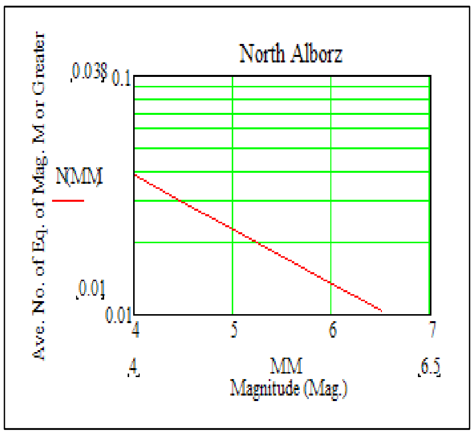
In the third step, the PGA values were calculated by Boore, Joyner and Fummal, Ambraseys 1995, Ambraseys & Bommer and Zare-Ashtiany attenuation relationships for various values of R, given in Table 4, and M, between m_0 and M_{max} with a value of 0.5 for Δm. For example, Figure 3 indicates the PGA values obtained from Zare-Ashtiany attenuation relationship for Mosha fault.



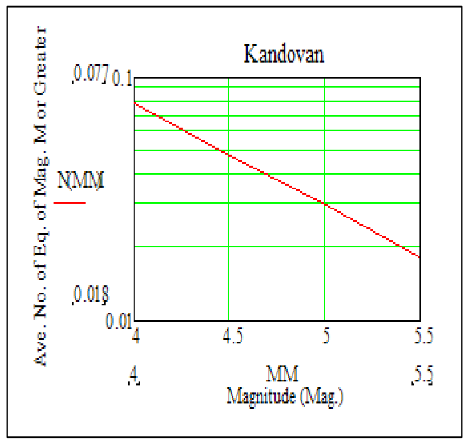
a) North Tehran *(α =–3.69, β =0.693)*



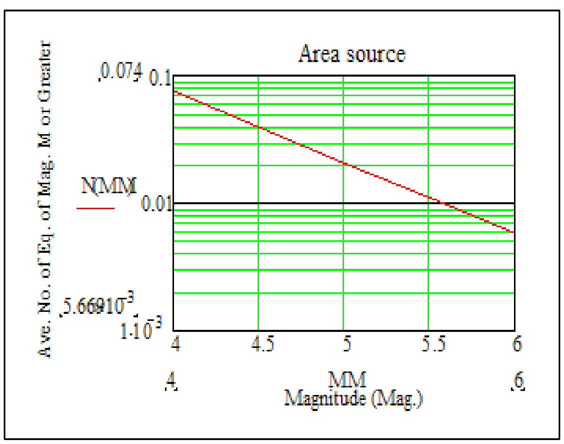
b) Mosha *(α =–0.554, β = 0.713)*



c) North Alborz *(α = –1.169, β = 0.526)*



d) Kandovan *(α = 1.324, β = 0.971)*



e) Area source *(α = 2.514, β = 1.281)*

Figure 2- Gutenberg-Richter relationships for the seismic sources

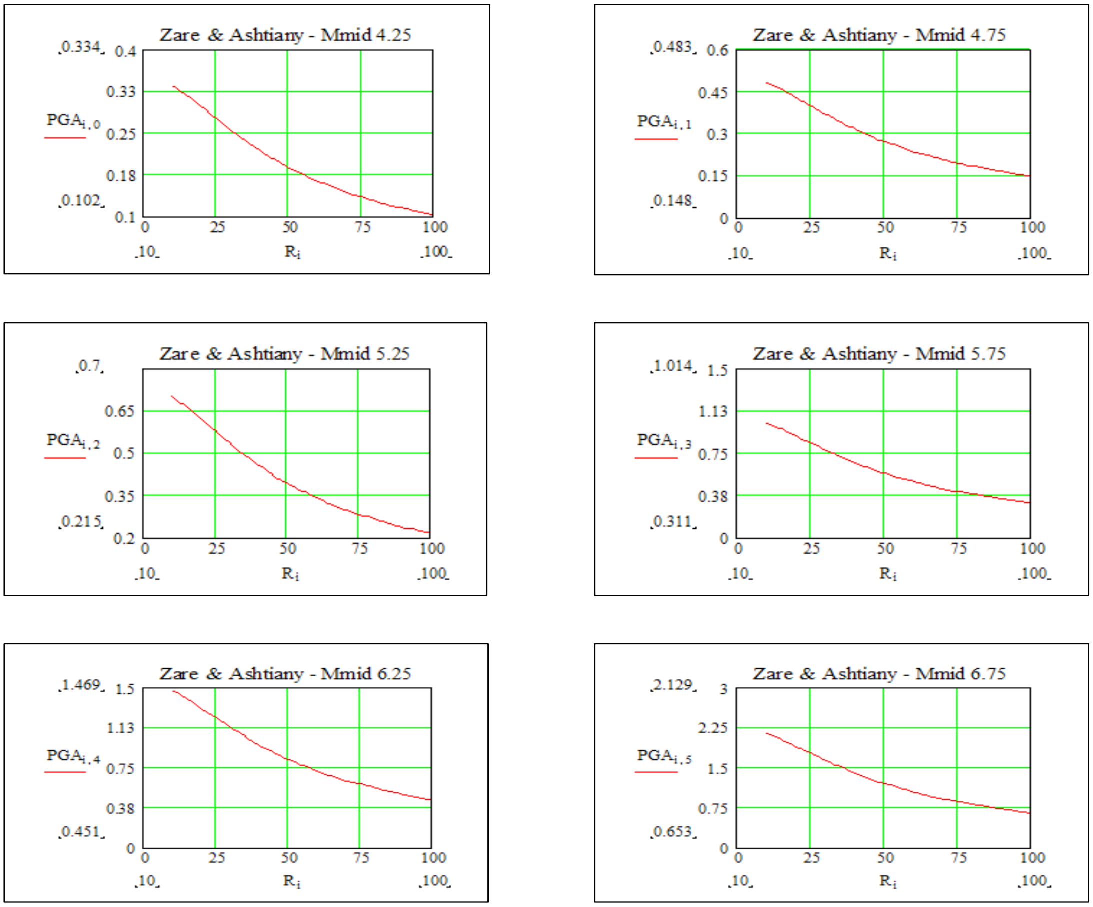


Figure 3- The PGA values obtained from Zare-Ashtiany attenuation relationship for Mosha fault

Given the occurrence rate of an earthquake, υ, the probability that the site PGA will exceed an acceleration value *acc* of interest were determined for every combination of discretized magnitude and distance for each source by using Equation (6).

$$P(PGA > acc | EQ : M, R) = 1 - \bar{\phi}\left(\frac{\ln(acc) - \lambda}{\zeta}\right) \tag{6}$$

where *acc*, varies from 0.5g to 0.65g with $\Delta\, acc$ is equal to 0.05g and

$$\lambda = E[\ln(PGA)] = mean \text{ value of } \ln\text{ (PGA)} \tag{7a}$$

$$\zeta = \sigma_{\ln(PGA)} \tag{7b}$$

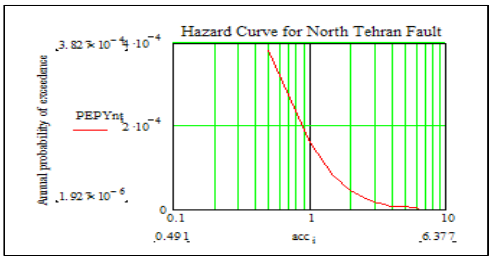
In the forth step, by using Equation (8) the probability of exceedence for each fault was obtained.

$$P(PGA > acc | EQ) = \sum_{R}\sum_{M} P(PGA > acc | EQ : M, R).f(M).\Delta m.f(R).\Delta R \tag{8}$$

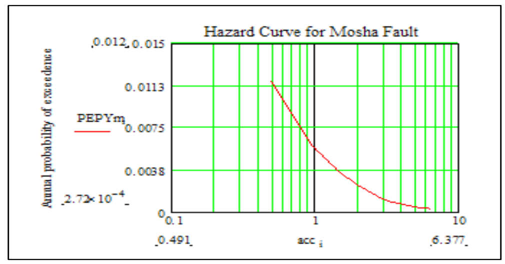
where the values of *f(R)*. ΔR are respectively 0.2 for Mosha fault, 0.25 for North Alborz and the Area source and 0.33 for North Tehran and Kandovan faults. The annual probability of exceedence for each fault was calculated by Equation (9).

$$P(PGA > acc) = 1 - \exp[-\vartheta t . P(PGA > acc | EQ)] \tag{9}$$

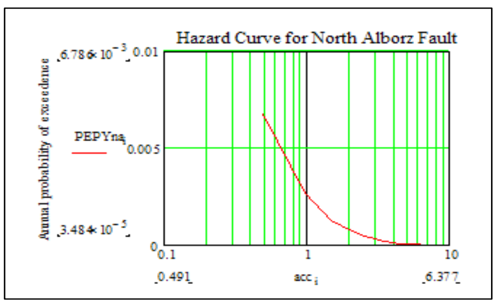
where t, equals 1.0 and υ, the average occurrence rate of earthquake for North Tehran, Mosha, North Alborz, Kandovan and Area source is 0.0008, 0.03, 0.029, 0.061 and 0.07, respectively. Figure 4 indicates the annual probability of exceedence obtained by Zare-Ashtiany attenuation relationship. Similar curves were obtained by the attenuation relationships mentioned above, which can not be presented here because of lack of space.



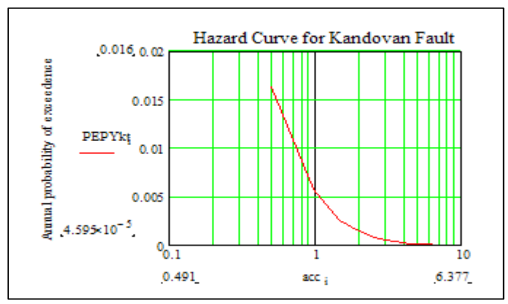
a) North Tehran fault



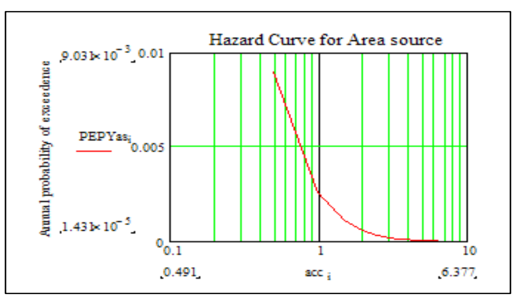
b) Mosha fault



c) North Alborz fault



d) Kandovan fault

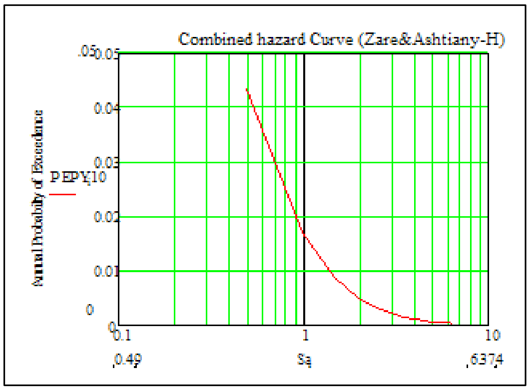


e) Area source

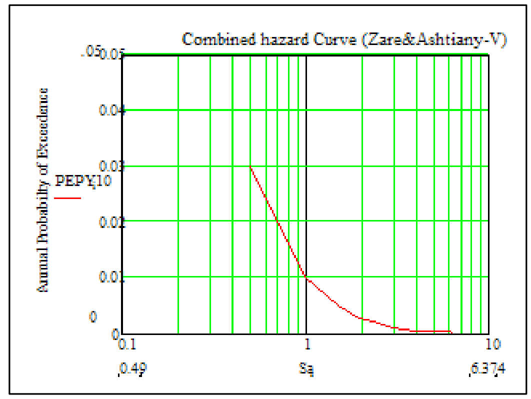
Figure 4- The hazard curve obtained for the seismic sources by Zare-Ashtiany attenuation relationship

Finally, as the fifth step, the results from the line faults and area source were combined by Eq. (10), [12]. The combined hazard curves for Zare-Ashtiany attenuation relationship for horizontal as well as vertical component and for the other attenuation relationships are shown in Figures 5 and 6, respectively.

$$P(PGA > acc) = 1 - \Pi[1 - P(PGA > acc)] \tag{10}$$

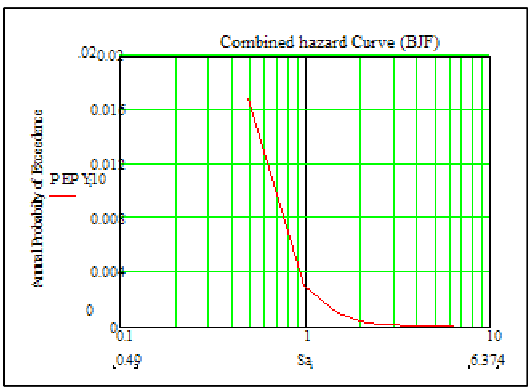


a) Horizontal component

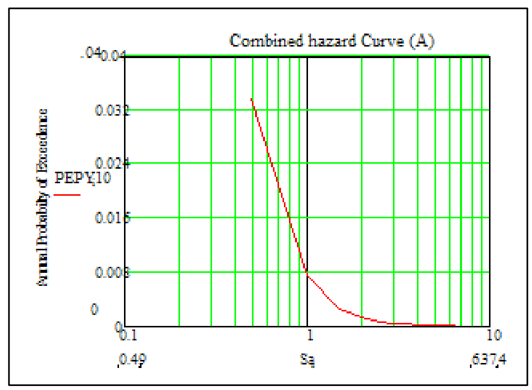


b) Vertical component

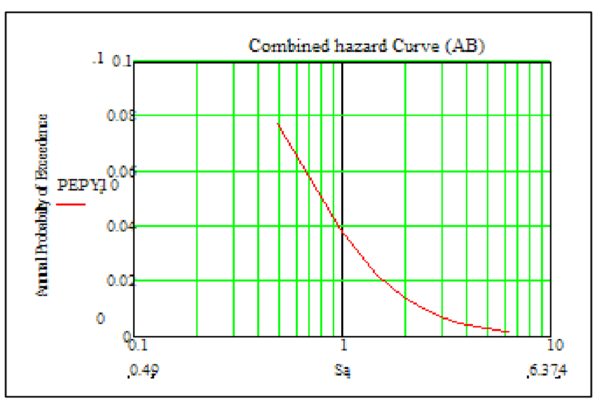
Figure 5- Combined hazard curves (Zare-Ashtiany attenuation relationship)



a) Boore, Joyner and Fummal



b) Ambraseys



c) Ambraseys & Bommer

Figure 6- Combined hazard curves (Boore, Joyner and Fummal, Ambraseys, and Ambraseys & Bommer attenuation relationships)

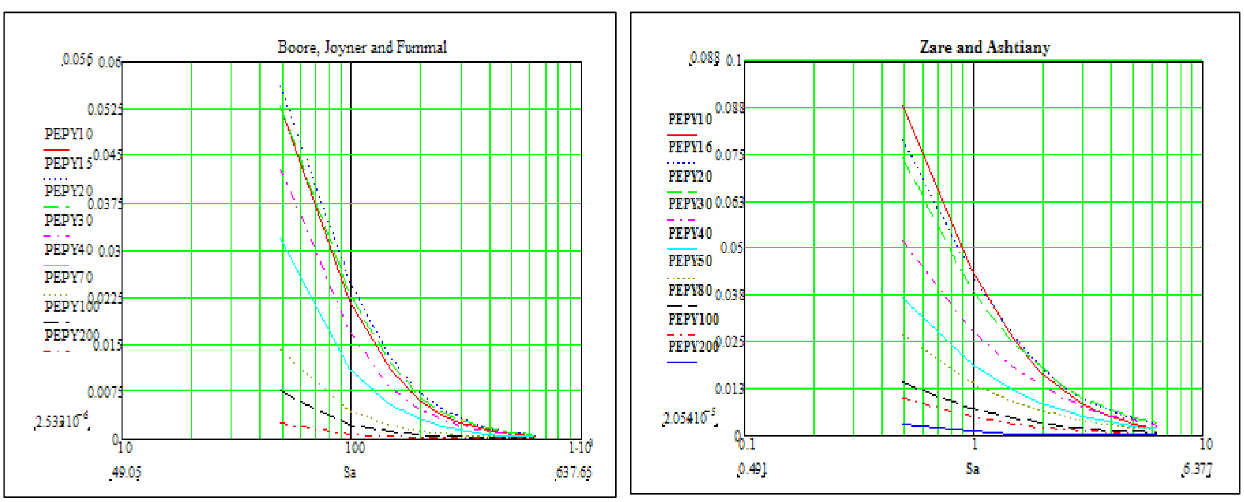
Table 5 presents the PGA values for 2% and 10% probability of exceedence in 50 years using linear interpolation.

Table 5- PGA values for 2% and 10% probability of exceedence in 50 years (in terms of g)

PGA		
10%	**2%**	**Attenuation Relationship**
0.112	0.198	*Boore, Joyner and Fummal*
0.161	0.278	*Ambraseys*
0.569	1.534	*Ambraseys&Bommer*
0.314	0.628	*Zare and Ashtiany (H)*
0.230	0.461	*Zare and Ashtiany (V)*

DEVELOPING THE UNIFORM HAZARD SPECTRA (UHS)

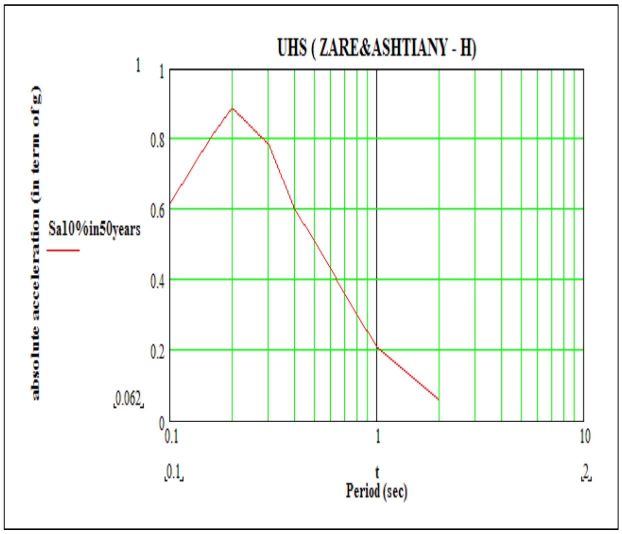
By definition the response at each discrete frequency of UHS has an equal probability of being exceeded. The steps involved in computing a UHS are the same as those for the probabilistic hazard curve described above, except that the steps are repeated several times using different coefficients corresponding to each discrete frequency. The Boore, Joyner and Fummal and the Zare-Ashtiany spectral attenuation expressions were used to compute the S_{pv} and S_a respectively. Each curve in Figure 7 shows the S_a (spectral acceleration) values for the period range of 0.1s to 2.0s. Figure 8 indicates the UHS curves for the 10% probability of exceedence in 50 years (Life Safety Level).

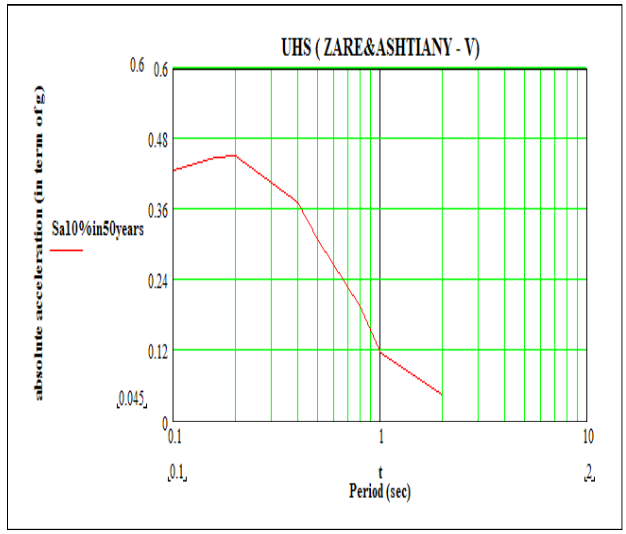


a) Boore, Joyner and Fummal

b) Zare-Ashtiany (H)

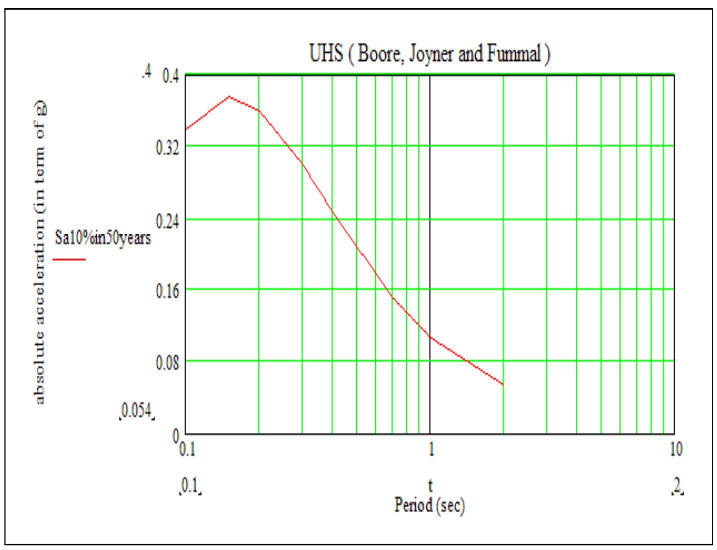
Figure 7- Probabilistic hazard curves vs. S_a for various periods





a) Zare-Ashtiany (Horizontal Component)

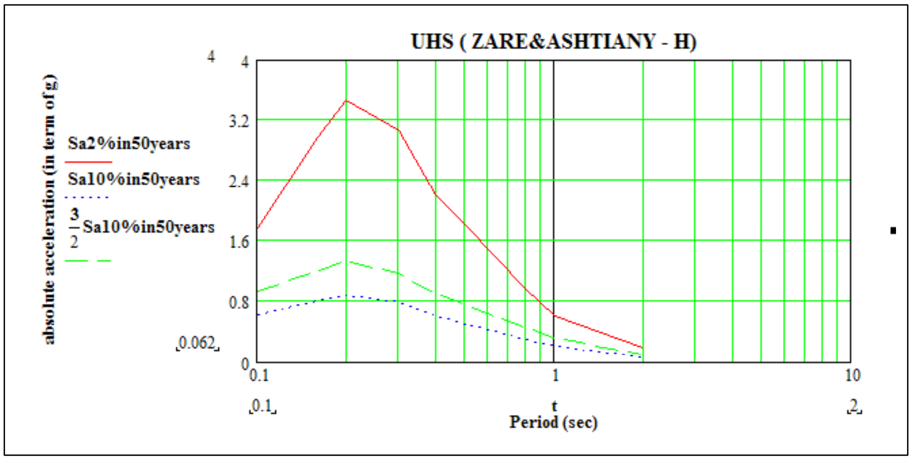
b) Zare-Ashtiany (Vertical Component)



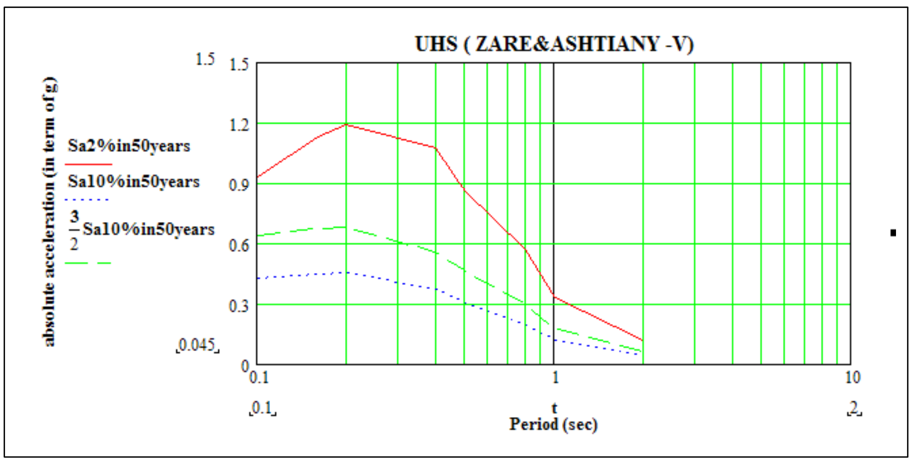
c) Boore, Joyner and Fummal

Figure 8- UHS curves for Life Safety Level (10% in 50Years)

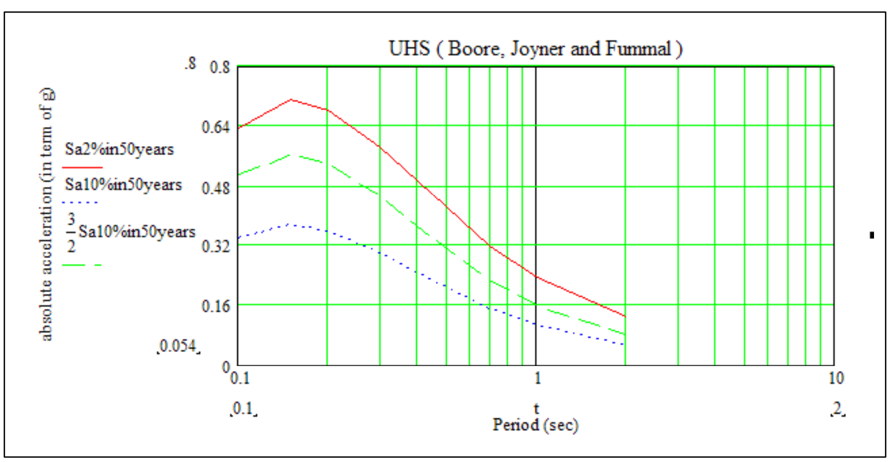
In Figure 9, UHS curves were drawn for 2% in 50 years (Collapse Prevention Level), 10% in 50 years (Life Safety Level) and 1.5 times the 10% in 50 years ground motions. Comparison of the 1.5 times the 10% in 50 years and 2% in 50 years spectra for the site indicates that if the building is designed for a 10% in 50 years ground motion, it would be much less likely to survive the 2% in 50 years ground motion.



a) Zare-Ashtiany (Horizontal Component)



b) Zare-Ashtiany (Vertical Component)



c) Boore, Joyner and Fummal

Figure 9- UHS curves for 2%, 10% and 1.5 times the 10% probability of exeedence in 50 years ground motion

CONCLUSIONS

In this study the PGA values obtained for the site by DSHA method was 1.75g, by PSHA method varied between 0.112g and 0.569g for 10% and 0.198g and 1.534g for 2% exeedence in 50 years ground motion depending on the applied attenuation relationship. The PGA for Vertical and Horizontal component using Zare-Ashtiany attenuation relationship was obtained 0.23g for 10% and 0.461g for 2% and 0.314g for 10% and 0.628g for 2% exeedence in 50 years ground motion, respectively. The ratio of Vertical to Horizontal component (V/H) is 0.73, while the building codes usually characterize the V/H equal to 0.67. This study has shown that V/H increases due to near fault effect.

It can be seen also that in general, the results of DSHA method are over estimated, because it uses not only the minimum site-to-source distance, but also the maximum magnitude of ground motions. The results of PSHA method are more reliable, because this procedure uses seismicity parameter and several site-to-source distances. Comparison of the 1.5 times the 10% in 50 years and 2% in 50 years UHS spectra for the site indicates that if the building is designed for a 10% in 50 years ground motion, it would be much less likely to survive the 2% in 50 years ground motion.

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