On seismic hazard analysis of the two vulnerable regions in Iran: deterministic and probabilistic approaches

2014 NZSEE Conference

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ABSTRACT: Seismic hazard analysis of vulnerable countries on the Alpine-Himalayan belt has great importance to be considered. Recently, Iran as one of the countries located on the stated belt has experienced a few number of severe earthquakes. A well-established index of how earthquakes affect buildings is by assessing probable Peak Ground Acceleration (PGA) which can be estimated by past events. For this reason, taking into account active faults around a city, and extracting seismic catalogues to categorize effects of surrounding faults on seismicity of the cities is a crucial step. The mentioned catalogues must be refined in both time and space to increase statistical independency of strong ground motion data, subsequently. There are two different approaches in estimation of PGA in seismic design of structures. Deterministic approach is unable to consider all characteristics of a site; however, the probabilistic hazard assessment which has been extensively used in recent years, applies a number of distinctive factors results in more accurate PGA evaluation. In this study, the two mentioned approaches have been conducted to investigate the seismicity of two vulnerable regions in Iran. For this purpose, 450 seismic catalogues has been used based on five different faults. Results show that DSHA method not necessarily suggests upper bound of PSHA one. Furthermore, the different attenuation relations used has great impact on results of site's Probable PGA due to considering a various number of effective factors. On the other hand, PSHA results have shown that, when faults divided into subparts lead to more accurate estimations.

1 INTRODUCTION

Iran as one of the most vulnerable countries located on Himalayan-Alpine seismic belt has experienced a number of ground motion events in last century. Figure 1 shows the density of these events in Iran for the recent 50 years. In this regard, the higher density of events on the south-west and middle-east of Iran necessitates the need for further investigation of these regions. For the last 100 years, there are at least 18 considerable earthquakes reported in Iran, among which the most catastrophic one was Bam earthquake (with M_w6.6). Although the magnitude of this earthquake was not significant, the mortality rate was substantial in the history of the country (Berberian, 2010). Kerman as one of the most historical and populated regions located in Iran has experienced severe earthquakes during last decades. Structures constructed in this region were not built according to seismic standards, most of the mud-brick buildings and the Ancient Citadel of Bam city was destroyed drastically after Bam earthquake; therefore, investigation of the highest probable peak ground acceleration (PGA) has a great value to be considered. South Khorsasan as another vulnerable region has suffered much as well, because of at least 3 destructive events during last 50 years. Birjand, the capital of stated province, once has experienced M_w7.3 earthquake caused 1500 people lost their lives. Table 1 demonstrates some major events occurred in past history of Iran (Tavakoli and Ghafory-Ashtiani, 1999). Consequently, Birjand and Kerman cities were chosen as two important vulnerable areas of this poorly constructed region for seismic hazard analysis in order to estimate probable PGA for enhancing design accuracy of structures.

In this research, we have studied 5 major faults located in south-eastern region of Iran for two adjacent provinces mentioned above. For these areas, the major active faults are Kuhbanan, Golbaf, Esfandiar, Dasht-e-Bayaz, and Nehbandan-e-Sharqi. Occurrence of significant events in history of this region,like Silakhor (with M_w7.4), Salmas (with M_w7.4), Tabas (with M_w7.7), Bam (with M_w6.6) and Saravan (with M_w7.7) have shown the significant seismicity of these two provinces in Iran.

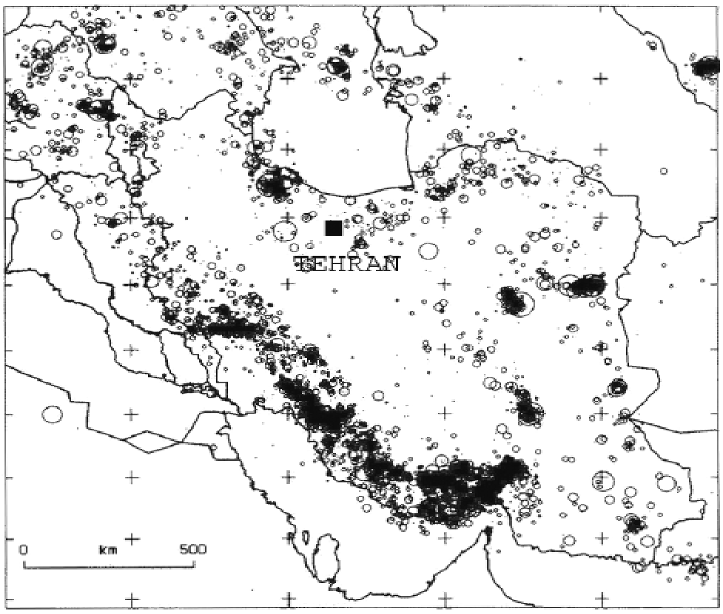

Figure 1. The recent density of events in Iran (Tavakoli and Ghafory-Ashtiani, 1999)

Table 1. The most drastic earthquakes in Iran

No.	Year	Location	Magnitude	Mortality
1	1909	Silakhor	7.4	8000 dead
2	1930	Salmas	7.4	2514 dead
3	1953	Torud	6.4	183 dead
4	1960	Lar	6.7	400 dead
5	1962	Buyin	7.2	10,000 dead
6	1968	Dasht-e-Bayaz	7.4	10,500 dead
7	1972	Qir	6.9	4000 dead
8	1977	Khorgu	7	128 dead
9	1978	Tabas	7.7	600 dead
10	1979	Qayen	7.1	130 dead
11	1990	Rudbar-Manjil	7.2	35,000 dead
12	1997	Ardebil	6.1	1100 dead
13	1997	Birjand	7.3	1500 dead
14	1997	Ghaen	7.3	1567 dead
15	2003	Bam	6.5	40,000 dead
16	2005	Zarand	6.4	612 dead
17	2012	Ahar-Varazaghan-Heris	6.4	306 dead
18	2013	Saraban	7.7	40 dead

2 COMPARISON BETWEEN DSHA AND PSHA METHODS

The probabilistic approach toward evaluating the probable peak ground acceleration of specified site could be avoided if we can find the worst case event which the deterministic method is based on. However, there is more complicated procedure for estimating the PGA of a site in order to resolve the attributed weak points in the usage of deterministic approach. The deterministic method presupposes the worst case caused by the highest magnitude event; however, the fact is that the worst case is strongly dependent of distance between the site and the occurred event (Baker, 2008); figure 2(a) shows two faults located in distinctive distances with different magnitude of occurred events, figure 2(b) indicates that for some lower periods, the closer events with less magnitude could have more response spectral acceleration.

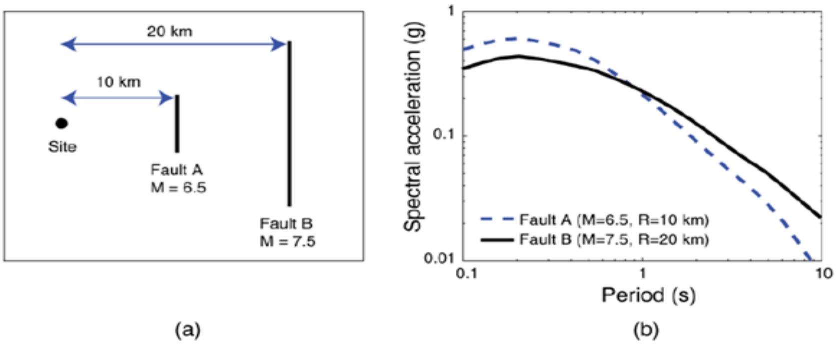

Figure 2. Effect of near medium ground motion versus far large ground motion (Baker, 2008)

Hanks and Cornell (2001) have done comprehensive research on PSHA procedure; they mentioned that the difference in PSHA and DSHA could be found in time and the probability. The concept of seismic hazard analysis is bounded with significant uncertainty. The major uncertain factors are magnitude and distance of earthquakes. PSHA method integrates the possible parameters to produce combinations; however, the DSHA considers the most unfavourable combinations to estimate the probable PGA at the site (Bommer, 2002). One of the crucial matters considered in PSHA method is that the attenuation relations is regarded for each part of the fault, and then integration would be performed; whereas, DSHA considers all events and does not implement any integration to evaluate the PGA. Despite stated fact, it does not necessarily mean that the DSHA method always has less accuracy than the PSHA approach; it indicates that PSHA could be more pragmatic to be used. "*The seismic hazard assessment of a region could not be achieved without enough number of deterministic elements based on valid scientific data, in that the application of logic-tree for enhancing the accuracy of results and handling epistemic probability associated with incomplete data could be beneficent*" (Bommer, 2002). Seismic hazard analysis should integrate both the deterministic and probabilistic characteristics of a region, since exclusion of effective factors result in misled judgment and prediction. The choice of method must be selected based on site characteristics, seismicity of region and the availability of data and future applications.

3 SEISMOTECTONIC

Active faults along Alpine-Himalayan seismic belt could be considered as the main characteristic of Iranian plateau. South-East part of Iranian plate collided with oceanic crust occurred in Mokran area. In this regard, eastern regions of Iran have experienced a number of catastrophic events during last decades. The Iranian plate is relatively rigid "triangle" whose surrounding plates grind, roughly from north east. They often remain wedged against each other for approximately long periods before sudden movement. In addition, south eastern areas could be affected by Arabian and Indo Australian interaction from different orientations leading to right-lateral shear; therefore, eastern parts may have possibly experience a considerable density of events.

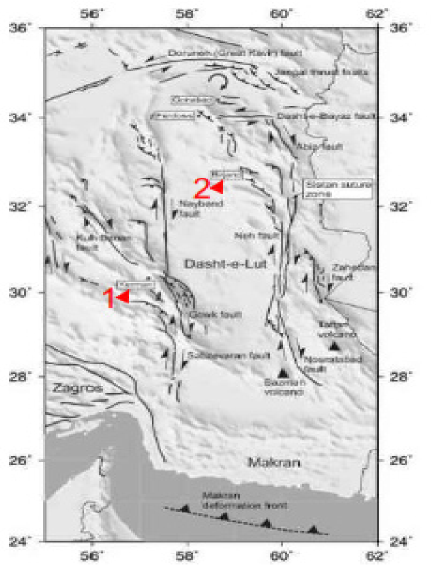

Figure 3. Effective Faults of South-Eastern Region of Iran

Based on the tectonic conditions of Iran, Ghodrati Amiri et al. (2003) have performed probabilistic seismic hazard analysis for two levels of return periods, for a city located in Iran. They further concluded that the PGA varies from 0.27g to 0.46g and 0.33g to 0.55g for 475 and 950 years, respectively. Walker and Jackson (2002) have worked on the eastern previously unrecognized faults of Iran. They further concluded that satellite imagery enhances the accuracy of future seismic decisions. Tavakoli and Ghafory-Astiani (1999) have performed PSHA analysis for some parts of Iran and developed %48 and %10 probabilities of exceedance contours corresponding to 75 and 475 years of return periods. They produced probable PGA maps with 0.25 degree intervals in both latitudinal and longitudinal directions. Mostafazadeh and Ashkpoor-Motlagh (2012) have evaluated south eastern seismic parameters of Iran according to fault rupture; they further prepared information about displacement time-history on the eastern region's faults. They determined major pulse duration from source time function, for Iran which could be used in rupture length evaluation. According to their evaluation, minimum and maximum displacement and stress drop along fault is changed from 0.15 to 3.5 meter and 3.2 bars to 79 bars, respectively.

4 SEISMICITY

Events could be categorized into two groups, the historical earthquakes (before 1900), and the instrumentally recorded earthquakes (after 1900). In this study, events occurred for the last 110 years in a radius of 100km from both cities as shown in figure 3 have been investigated. More than 300 catalogues were considered, the catalogues were gathered from the International Institute of Earthquake Engineering and Seismology[1]. All the data were refined with respect to time and space based on Knopov-Gardner[2] method to filter the main shocks from foreshocks and aftershocks. From the total of 15000 events, 1360 independent events were selected with respect to K-G method. These main shocks were filtered again with respect to distance and time of occurrence (Table 2). Moreover, the implemented catalogues have different magnitude scales, since it was announced by different procedures; therefore, all the catalogues' magnitude scales were changed to M_w as representative of events' magnitude. In this study, two distinctive sites have been considered for SHA[3] analysis as shown in the Figure 3. In addition, the characteristics of soil condition at the studied sites were extracted from IIEES reports to be used in attenuation relations.

[1] IIEES
[2] K-G method
[3] Seismic hazard Analysis

Table 2. Active faults in south-eastern of Iran

No.	Earthquake	Type	SRL	M_{max}	M_{min}	Events (K-G Refined)
1	Esfandiar	Thrust-Inverse	47	7.04	4	40
2	Dasht-e-Bayaz	Thrust-Inverse	88.5	7.37	4	139
3	Nehbandan-e-Sharghi	Thrust-Inverse	79	7.28	4	34
4	Kuhbanan	Thrust-Inverse	99	7.44	4	65
5	Golbaf	Thrust-Inverse	37	6.90	4	38

5 DETERMINISTIC APPROACH

In this study, Sadigh and Campbell attenuation relations (Naeim, 2001) were used to estimate PGA of mentioned cities. Additionally, In order to evaluate the relationship between fault characteristics and maximum earthquake magnitude two formulas have been implemented:

- Nowruzi (1985)

$$M_s = 1.259 + 1.244 \log L \tag{6}$$

where L is the length of the fault; and Ms is the surface magnitude. On the other hand,

- Wells and Coppersmith (1994)

$$M_s = a + b \log SRL \tag{7}$$

where a, b are fault-mechanism parameters. For instance, in reverse faults these parameters are 5 and 1.22, respectively. SRL is also surface rupture length.

The faults were categorized to area and line seismogenic sources due to the distribution of events. If the events allocated to each fault are widespread enough, the fault could be assumed as an area fault, whereas the line source is a fault with more focused distribution of events. In this study, the Kuhbanan, Golbaf, and Dasht-e-Bayaz faults are assumed as area sources and the Esfandiar and Nehbandan-e-Sharqi are defined as line sources. The DSHA method results are indicated in table 3.

This approach has three general steps to be completed:

- Recognizing events: all the node, line and area seismogenic sources in the vicinity of the site should be detected; in other words, for each seismogenic source the magnitude and distance of events should be gathered.
- Determining the maximum considered earthquake[4]: in this step the MCE should be distinguished, and for each source a pair of (M,R) would be produced.
- Choosing attenuation relations: attenuation relations are selected in order to estimate the PGA for each representative of (M,R).

$$a = F(M, R) \tag{8}$$

Table 3. Results of deterministic method

Source	R (km)	M	PGA(g) [Campbell]	PGA(g) [Sadigh]
Nehbandan-e-Sharqi	12.7	7.28	0.29	0.35
Dasht-e-Bayaz	16.4	7.37	0.27	0.31
Kuhbanan	35.5	7.44	0.15	0.16
Golbaf	40.2	7.15	0.11	0.12
Esfandiar	141.7	7.04	0.02	0.016

[4] MCE

6 GUTENBERG-RICHTER[5] LAW

For estimation of the probable PGA, after catalogue refinement, events were sorted in order to determine the number of events with more than a certain magnitude. The occurrence-magnitude curve was developed for each seismogeneic source.

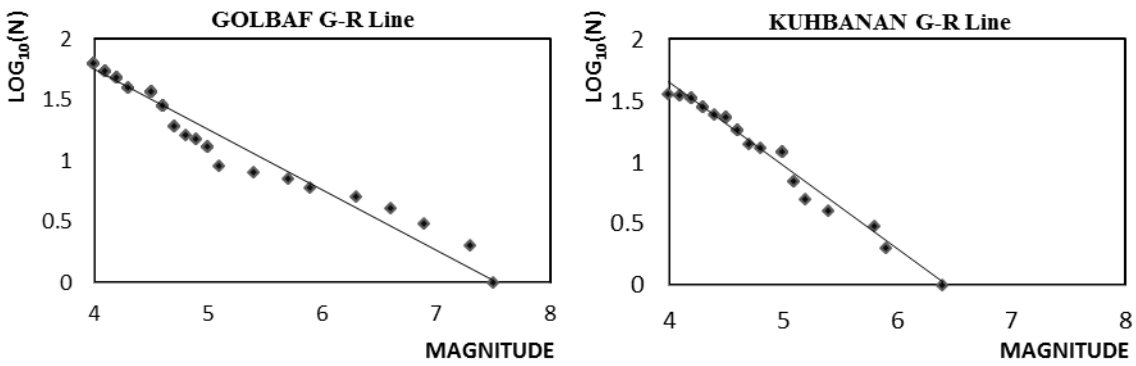

Figure 4. G-R lines for the seismogenic sources of Kerman city

To produce G-R relationship, the scattered points were fitted with a line based on the least squares method. The following formula has been established according to occurrence-magnitude graphs:

$$\log(N) = a - bM \tag{9}$$

where a, b are constants, representative of the entire rate and potential of seismicity. Figure 4 indicates the G-R relationship parameters for two out of five seismogenic sources.

7 PROBABILISTIC HAZARD ANALYSIS

The nature of earthquake events necessitates probabilistic approach to perform quantitative judgment. The highly variable earthquake occurrences have some consistent average behaviour; therefore, our accurate assessments should be based on probabilistic terms. As opposed to DSHA, probabilistic method considers the uncertainty and likelihood of an event as well as the ground shaking attenuation models. In this section, a MATLAB-based code for conversion each PGA to a certain magnitude was developed based on attenuation relations. Ultimately, for each PGA regarding distance between source and site, a magnitude was calculated. By implementing the G-R law, the density of events' occurrence per area/length was evaluated. Moreover, the effective life span of structures assumed to be 50 years.

The probability of exceedance could be assessed by the following formula:

$$\text{For Area Seismogenic Source}: P(PGA \geq a) = 1 - e^{\sum N'(M) A T_L} \tag{10}$$

$$\text{For Line Seismogenic Source}: P(PGA \geq a) = 1 - e^{\sum N'(M) L T_L} \tag{11}$$

where T_L is the assumed life span of structures, $N'(M)$ is the density of events per unit area/length and A and L are the area and length of the fault, respectively.

Each seismogenic source was divided into distinctive parts, since the distance of each subpart from the site varies along the fault; this division enhance the accuracy of ultimate probable PGA, especially when the length/area of each fault is significant. For instance, the Kuhbanan fault with approximate 2000 square kilometres was divided to 20 subparts, and the distance of each part from the site was further assessed for attenuation relations.

The obvious difference between DSHA and PSHA methods could have two main reasons. First, in the DSHA method, the Wells and Coppersmith formula was implemented for evaluation of surface magnitude; however, if the region is seismically active and the numbers of higher magnitude events are significant, the higher POE may be expected for each PGA. Second, if a fault experiences an event

[5] G-R relations

with highly significant magnitude, the slope of G-R line would be reduced substantially leading to higher PGA estimation for an assumed POE.

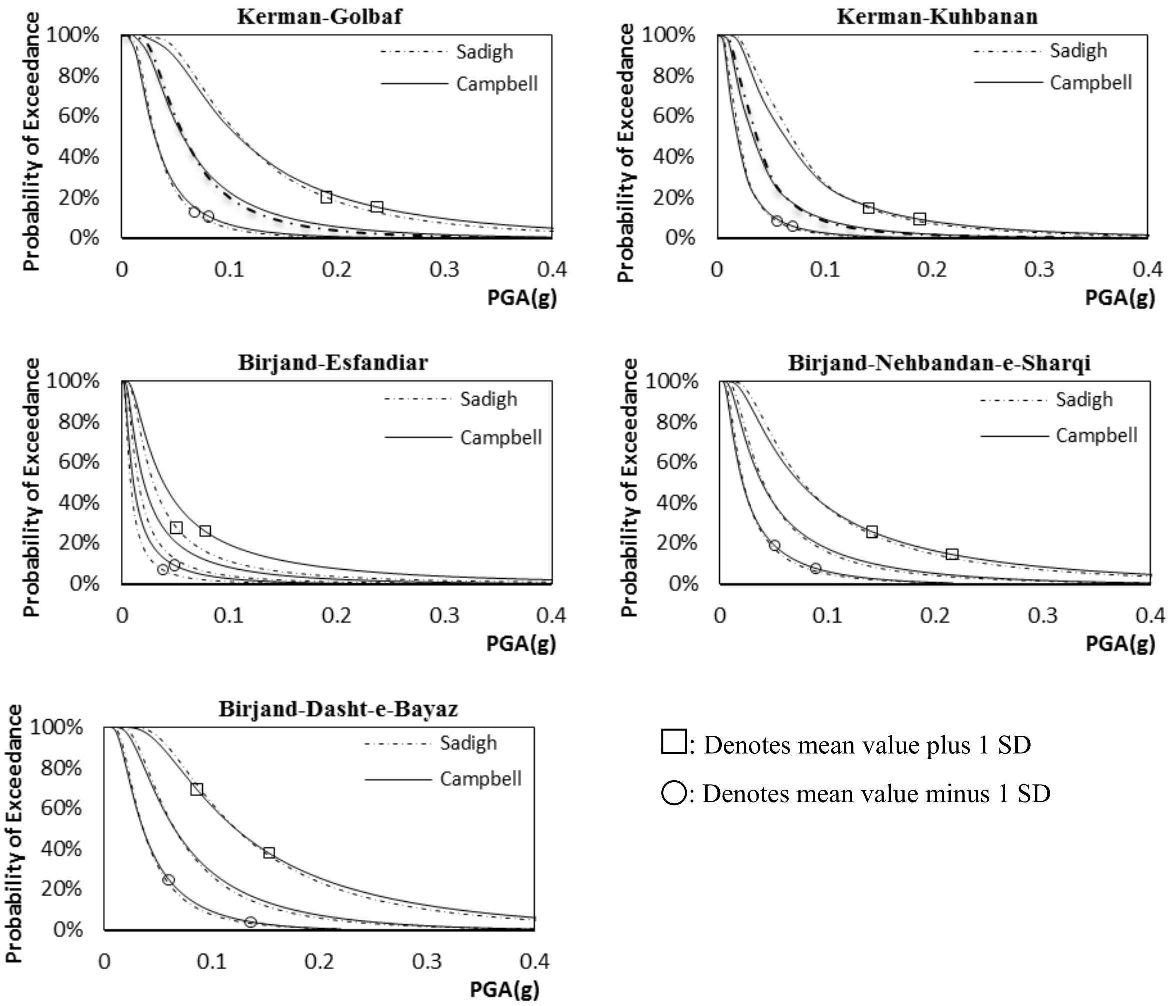

Figure 5. PSHA curves for each individual sources based on Sadigh and Campbell relations

As indicated in Figure 5, the Campbell attenuation relation indicates higher values for PGAs more than 0.1g considering a specified POE of the investigated regions. In addition, combined probabilistic curves indicated in Figure 6 shows higher values compared to probabilistic curves attributed to each fault due to the fact that for an assumed PGA, it is enough only one of the faults located in a region to be activated. It is clear that utilizing the combined PSHA curves would lead to more conservative and rational results.

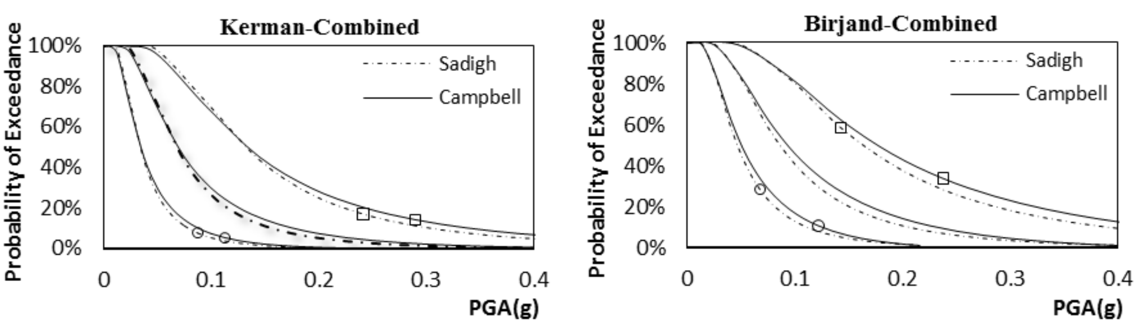

Figure 6. PSHA curves of each city based on Sadigh and Campbell relations

8 CONCLUSION

This paper investigated seismic hazard of Kerman and Birjand as two major cities of south eastern of Iran based on probabilistic and deterministic approaches. The main results of this investigation are as follows:

In probabilistic approach, for the 2% POE, the probable PGA of Birjand and Kerman as for median PGA prediction are 0.36g and 0.31g, respectively. On the other hand, in deterministic method the estimated PGA for the stated cities is 0.27g and 0.13g, respectively. It has been observed that the PSHA approach may results in higher PGA values compared to DSHA; therefore, the later method not necessarily leads to more conservative PGA calculations.

Application of different attenuation relations might lead to a significant discrepancy in POE curves. In this regard, for the POE of 9%, the PGA is 0.24g in the case of Campbell attenuation relation; however, this value has been estimated 0.2g by Sadigh attenuation relation, as illustrated in figure 6. In addition, it has been observed that for POE of 3%, the PGA for Kerman city according to Campbell and Sadigh attenuation relations are 0.3g and 0.26, respectively.

REFERENCES

Baker J.W. 2008. An Introduction to Probabilistic Seismic Hazard Analysis (PSHA). Version 1.3, Stanford University.

Berberian, M. 2010. Bam Earthquake. Digital Version 2010. In Encyclopaedia Iranica. New York: Centre for Iranian studies, Columbia University.

Bommer, J.J. 2002. Deterministic vs. Probabilistic Seismic Hazard Assessment: An Exaggerated and Obstructive Dichotomy. *Journal of Eartquake Engineering*, Special Vol 6(1): 43-73 London: Imperial College University.

Ghodrati Amiri, G. & Motamed R. & Rabet ES-Haghi H. 2003. Seismic Hazard Assessment of Metropolitan Tehran, Iran. *Journal of Eartquake Engineering*, Vol 7(3): 347-372 London: Imperial College University.

Hanks, T. C. & Cornell, C. A. 2001. Probabilistic seismic hazard analysis: a beginner's guide. *Earthq. Spectra*, submitted.

Mostafazadeh, M. & Ashkpoor Motlagh, S. 2012. Source Study of Some Large Earthquakes Occurred in South Eastern Iran. *JSEE*, Vol 14(4): 285-296 Tehran: International Institute of Earthquake Engineering and Seismology.

Naeim, Farzad. 2001. *The Seismic Design Handbook*. Springer; 2nd edition.

Tavakoli, B. & Ghafory-Ashtiany, M. 1999. Seismic hazard assessment of Iran. *Annali Di Geofisica* (The Global Seismic Hazard Assessment Program), Vol 42(6): 1013-1021.

Walker, R. Jackson, J. 2002 Offset and Evolution of the Gowk Fault, S.E. Iran: A Major Intra-Continental Strike-Slip System. *Journal of Structural Geology*, Vol 24: 1677-1698