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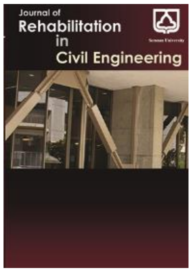

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Seismic Hazard Analysis and Obtaining Uniform Hazard Spectra for Esfahan Region, Iran

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ABSTRACT

The present study was conducted to determine peak ground acceleration (PGA) over bedrock in probabilistic analysis methods for the seismic hazard and uniform hazard spectra at different hazard levels for Esfahan city. A series of statistics containing historical and instrumental seismic data covering from the 8th century A.D. to the now up to a radius of 200 km was employed and seismic sources were modeled up to a radius of 200 km from Esfahan city. For this purpose the method proposed by Kijko was employed considering uncertainty in magnitude and incomplete earthquake catalogue. Seismic hazard analysis is then carried out for Esfahan city by using SEISRlSK III program for 11×13 grid points. Four different attenuation relationships of PGA and SA with logic tree were used to determine the PGA on bedrock. The PGA can be determined for 143 points and the hazard spectra can be specified for 20 points of the city. Covering %2 and %10 probability of exceedance in one life cycle of 50 years are presented. Finally, the uniform hazard spectra was also presented with %10 and %2 of probability of exceedance in one life cycles of 50 years are presented along with New Mark and Hall Spectra.

1. Introduction

Iran is located in a high-risk seismic zone, but its seismicity intention is not the same in all parts. Iran is a country where earthquake causes many financial and life losses. Locating in Alp – Himalaya seismic belt, Iran has a devastating earthquake per year. The specification of some cataclysmic earthquakes like Bouin-Zahra (1962), Dashte Baiaz (1967), Tabas (1978), Manjil-Roudbar (1990) and Bam (2003) support the significance of the issue. Esfahan province is located in a special seismotectonic conditions; thus it includes different relative seismic hazard ranges. Since Esfahan city (as the center of Esfahan province) is one of the important industrial cities of Iran, including several infrastructures such as power plants and historical places, special seismic investigations are necessary. Geological features in most parts of Esfahan are very similar, as a surface silt layer with gravel and coarse grain stone is extended in most parts and usually dig under construction. Beneath this surface layer, alluvium layers, with different grain sizes, sorting and relative good compaction are shown. In compaction point of view and because surface soil layer is removed during construction, geologically it could be classified in relatively hard soils. In Iranian Code of Practice for Seismic Resistant Design of Buildings (BHRC) [1], lateral force on structures due to earthquake is calculated by equivalent static force method or dynamic analysis methods. Each of the methods has its own specific application. In an earthquake equivalent static force method, base minimum shear force or earthquake side integrated forces in each trend of the structure is calculated as below:

$$V = C.W \tag{1}$$

Where, V is base shear force, W is total weight of structure and C is an earthquake coefficient that is calculated as below:

$$C = \frac{ABI}{R} \tag{2}$$

Where, A is design basis acceleration ratio (earthquake acceleration over gravity acceleration, g), B is structure response factor that is obtained from design response spectra, I is structure importance factor and R is structure behavior factor.

The value of A, as a main component of Eq. (2), is proposed to be 0.25g for the region containing Esfahan city by Iranian Code of Practice for Seismic Resistant Design of Buildings (BHRC) [1]; however by considering the importance of the city cause of including many infrastructures, investigation with more details and accuracies are necessary for calculating A (design basis acceleration). Furthermore, updating seismicity data and completing these information in addition to new scientific researches, require more hazard analysis in this region, and new analysis with updated data variations could provide demands of studies. Few researches were done in geology, seismotectonic structure and seismicity of central Iran, some of which has covered Esfahan province. Esfahan province in Iran's seismotectonic structure maps such as Berberian [2], Nougol [3] is located in a place that its southwestern and western parts are more dynamic. Main earthquakes were occurred within 200 km radius of Esfahan city and their presence has significant affects to the studied region. The main earthquakes affected the area of Esfahan city include: in 1052 AD (magnitude of Ms=6.8), in 1666 AD (magnitude of Ms=6.5), in 1844 AD (magnitude of Ms=6.4), in 1876 AD (magnitude of Ms=6.8). The closest earthquake in surrounding Esfahan (about 127 km distance to Esfahan) was occurred in 1854 AD (magnitude of Ms=5.5).

2. Seismotectonic Structure of Esfahan

With different types of earthquake sources in the world such as volcanoes, faults and etc., today faults are recognized as the main earthquake sources for Iran. Consequently, studying faults are one of the basic steps for seismotectonic and relative seismic hazard macro zonation studies.

According to existing earthquakes data in Iran, most faults are concentrated in Zagros Belt length while number of faults in central and eastern parts is lower. Thus, there are

many different damage places against devastating earthquakes. Seismotectonic structure of Esfahan is influenced by Iran plate tectonics conditions in the Middle East.

Main existing faults in the region and provance include: Zefreh, Daran, Varzaneh, Tiran, Gandoman, Hafshejan, Mobarakeh, Pirbakran, and etc. faults. Table 1 shows list and features of these faults. Note that, Nowroozi[4] equation is used to calculate Mmax. In Fig. 1 locations of faults in Esfahan region and province are shown.

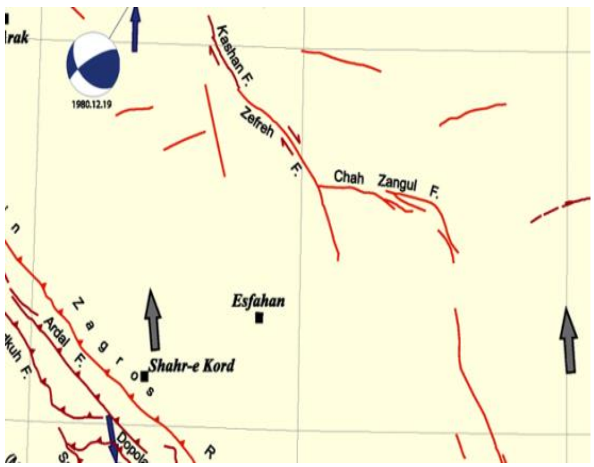


Fig. 1. Active faults of Esfahan (IIEES) [5]

Table 1. Main active faults of Esfahan

No.	Fault	Type	Length (km)	M max
1	Zefreh	Thrust-Inverse	105	7.5
2	Daran	Thrust-Inverse	110	7.5
3	Chah zangul	Thrust-Inverse	100	7.4
4	Gandoman	Thrust-Inverse	85	7.3
5	Hafshejan	Thrust-Inverse	70	7.2
6	Mobarakeh	Thrust-Inverse	35	6.8
7	Pirbakran	Thrust-Inverse	15	6.3

3. Seismicity of Esfahan

Earthquake history shows its seismicity position. To access seismotectonic structure features, there must be a complete study list collection of earthquake occurrence in each region. Occurred earthquakes in the studied region and province may be categorized in two classes: (1) historical earthquakes (occurred once before 1900 AD) and (2) instrumental earthquakes (occurred after 1900AD). These earthquakes are considered as natural economy social devastator catastrophes. Thus, many writers, historians, tourists, political, social leaders and journalists have written these events and now we may find these clues in historical books.

Historical seismicity also in Persian traditional civilization has been mentioned.

Because just we read the history of earthquakes based on ancient written books, accuracy and precision of these records is a subject to writers trust. Historical earthquake magnitude is based on its damage, ranges of influence and other elements, which may be compared to recent earthquakes data. Some studies have implemented for proper and comprehensive earthquakes catalogue collection. Researchers like Berberian[6], Ambraseys and Melville[7], have researched about collecting and editing seismic data. Among all Iran's historical earthquake reports, collected set of Ambraseys and Melville[7], has uniform and homogeneity form, compared to other data. Esfahan city as a capital city of Esfahan province is placed in central tectonic state, and in this study, historical earthquake data for this region and province were collected.

4. Esfahan Seismicity Parameters

Seismic estimation is carried out based on occurred earthquakes data in the studied region using probabilistic methods. Earthquake catalogue in 200 km-radius of Esfahan and supposing earthquakes follow Poisson distribution are collected and provided. Kijko[8] method was used to calculate seismicity parameters, return period and earthquake occurrence probability.

5. Seismicity Catalogue

The catalogue in this paper was used to collect information about seismicity occurrences from data range and a determined radius of studied region. Thus, one earthquake series collected and selected, which was in 200 km distance around Esfahan. Using probabilistic methods and other references due to data insufficiency especially earthquake depth and magnitude data was inevitable.

Some studies were carried out to collect Iran's historical earthquakes data (historical earthquakes refer to occurrence before 1900 AD) Including investigations by Ambraseys and Melville[7] who wrote down Iran's historical earthquakes history and Moinfar, et al[9] who has collected historical and instrumental earthquakes set moreover, there are other catalogues for the studied region such as "The National Earthquake Information Center (NEIC)" and "International Seismological Center (ISC)". After collecting final earthquake catalogue, aftershocks, foreshocks and incorrect recorded events would be removed from it (Appendix A). Therefore, filtered data follow Poisson process. Method of omitting aftershocks and foreshocks was time domain and space domain variable windows method, which helps to show better independency of earthquakes. The method which is used to eliminate the foreshocks and aftershocks is the variable windowing method in time and space domains by Gardner and Knopoff[10].

One of the advantages of this investigation is that collected and filtered catalogue contains earthquakes with various magnitudes. Scale of magnitudes included in this catalog is Richter local magnitude scale (ML), Surface wave magnitude scale (Ms) and Body wave magnitude scale (mb). Other scales convert to Ms.

6. Earthquake Magnitude

Generally, when calculating seismic hazard analysis, Ms or mb is used as a magnitude scale, but because of magnitude scale incompleteness in earthquake lists, compensating this failure is required. The best statistical method of this case is Least Square statistical method and finding best fit line among Ms and mb recorded data. In this investigation, based on insufficient earthquakes that both Ms and mb have recorded data, the following relation (IRCOLD) [11] is used:

$$M_S = 1.21m_b - 1.29 \quad (3)$$

7. Determination of Seismic Parameters

To find seismicity nature of each region, estimating seismicity parameters is considered as a principle seismicity of that region. Seismicity parameters determination calculation is based on earthquakes occurrences and their magnitude frequency relationship. Until now, various methods of estimating the seismicity parameters have been carried out totally based on primary Gutenberg-Richter[12] relation.

While these parameters are very important in seismic hazard analysis and determination, in this study Kijko method is used that is based on Gutenberg Richter double truncated distribution function and maximum likelihood statistical estimation method. Assumptions where must include and consider in this project performance are as below:

Following earthquakes from Poisson process, that means earthquake independency from each other in time domain and space domain.

Seismicity homogeneity of the studied region and having seismicity features in 200 km range of Esfahan city.

Notably, because second condition is uncertain in some cases, a seismic study of Tavakoli[13] has also been used in this research to improve Logic Tree method results.

8. Evaluation of Seismic Parameters by Kijko Method

While errors of seismicity data in the studied range in different times in current century are not the same and also because of insufficient seismicity data and low level of existing data accuracy, primary Gutenberg Richter method and fitting result values do not provide appropriate answers. Thus, a compatible method with Iran's seismicity data was used. Maximum likelihood estimation method that was used at the first time by Kijko[8] was a relatively simple model of assessing seismicity parameters.

In the study, seismicity parameters were not calculated for each source, but mentioned parameters were obtained for Esfahan city and province with 200 km-radius.

Kijko program which has formed based on extreme distribution function for historical earthquakes with low accuracy and high magnitude. Gutenberg Richter double truncated distribution function for instrumental recorded earthquakes and maximum likelihood estimation are applied. Based on this program, three earthquake groups have been considered in this paper as below:

Historical earthquakes that magnitude error for different time periods has mentioned 0.3 and 0.4 of magnitude scale; 0.4 error for earthquake magnitudes between 600 AD and 1400 AD, and error of 0.3 for earthquake magnitudes in time range of 1400 AD and 1900 AD

Earthquakes that occurred before global seismograph network installation (from 1900 to 1963); their magnitude of error is considered 0.2 magnitude scale and also threshold magnitude is 4.5.

Instrumental earthquakes from 1963 till now, that have recorded with good precision and have lower errors. 0.1 error magnitude and threshold magnitude of 4 are considered for these earthquakes.

To investigate seismicity trend in this region in current century and previous centuries, Kijko [14] method is used in three separate cases and results are shown in Table.2 In the first manner, just historical earthquakes are used. In the second case, only earthquakes of the twentieth century are used for seismicity parameters estimation, and in the third one, combination of historical earthquakes, extreme value distribution and double extreme distribution function of the instrumental earthquakes are used. Table.2 shows result values of B (b × ln10) and λ for each case. With respect to other methods, Kijko method has obvious and tangible benefits for historical and instrumental data combination and also it can estimate how much error would be introduced in the calculations (with neglecting each time interval or its incorrect combination). In Fig. 2, annual rate of occurrence, λ, for earthquakes with magnitudes greater than 4 was shown.

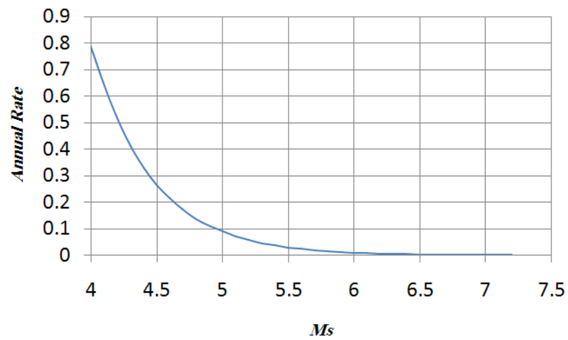


Fig. 2. Annual rates estimated by Kijko method for Esfahan

It is worth to mention that in computer derived SEISRlSK III [15] that is used to calculate PGA; an important required parameter is annual rate. Furthermore, using historical earthquake lists (to increase time range of listed occurred earthquakes and increase validity of the results) and lists of instrumental earthquake (with respect to their accuracy and more completeness) leads to results validity improvement in this part. The main emphasize was on synchronized usage of these earthquakes and all calculations based on seismicity parameters (λ and b) obtained from third case.

Table 2. Seismicity parameters in different cases for Esfahan

Catalogue	Parameter	Value	Data Contribution to the parameters (%)		
			<1900	1964-1900	1964<
Historical Earthquakes Data	Beta	2.28	100	-	-
	Lambda(Ms=4.5)	0.19	100	-	-
Instrumental Data	Beta	2.09	-	30.3	45.3
	Lambda(Ms=4.5)	0.79	-	13.1	86.9
Historical and Instrumental Data	Beta	2.23	44.1	22.7	33.3
	Lambda(Ms=4)	0.76	9.8	11.7	78.5

In this study, seismicity parameters by Tavakoli [13] method were also used. Table.3 shows suggested values for Esfahan's seismicity parameters. By these two methods, it may compensate some failures of insufficient accurate data.

Table 3. Seismicity parameters for seismotectonic province of Esfahan

Province No.	Span of Time	β	M max	Lambda
9	1922~1995	1.94 ± 0.16	7.3 ± 0.3	0.71

9. Seismic Hazard Analysis

Seismic hazard analysis with respect to seismic levels application in design is carried out in probabilistic ways. In deterministic method, based on known seismic sources and without considering an event probability, maximum land slide parameters with attenuation model are calculated and estimated in mentioned structure. In the probabilistic method that is used in this study, analysis is done by mentioned seismicity range, seismicity sources, and seismicity λ and β parameters studies. Then, based on how big is magnitude and how far to structure (base) with attenuation model, maximum land slide parameters of the earthquake is estimated in mentioned structure. In this study, probabilistic method was used to estimate Peak Ground Accelerations.

To estimate acceleration parameter and analyzing seismic hazard correctly, it is necessary to follow these procedures:

Selecting proper attenuation relationship;

Modeling seismic sources;

Estimating potential seismicity of each source;

Identifying the type of structure soil

These 4 steps are actually identifying ideal bedrock in seismic hazard assessment which is used in this study.

10. Attenuation Relationship

Attenuation relationships are one of the most important elements in the seismic hazard analysis which represent the relationship between peak ground acceleration, the distance from the surface epicenter of the earthquake and the magnitude. Selection of the most proper model among the various attenuation models of the strong ground motion is done based on following criteria:

The relationship can be applicable for the studied region.

The distance of the site or sites from the seismic sources must be in the determined maximum and minimum range of the relationship.

The earthquake magnitude scale of the region is as the same as the magnitude scale in the relationship.

The maximum and minimum values of earthquake magnitudes in the region are the same as the magnitudes from relationship.

The focal depth of earthquakes of the region must be in the range of the attenuation relationship.

The soil type of the studied region and the attenuation relationship must be the same.

The mechanism of the most seismic sources of the studied region must be the same as the mechanism of the attenuation relationship

Generally, functional form of attenuation relationships is selected to reflect better landslide process. This causes minimizing experimental coefficients (factors) and more reliability of attenuation relationships applications in weak terms (distances and sizes) which are provided in base data.

Eq. (4) expresses general form of attenuation relationship:

$$\log Y = a + F_1(M) + F_2(R) + F_3(s) + \varepsilon \qquad (4)$$

Where, Y means the strong ground motion parameter and directly relates to magnitude M and reverse relationship to distance R. Attenuation relationships coefficients are usually obtained experimentally from statistical models of accelerograms. a is a constant factor and ε is the random error with mean value of zero which is a standard deviation to express Y uncertainty. Mathematically it may model other parameters such as site conditions, fault mechanism, alluvium and sedimentary layer thickness, and form them in general function of F3(S) in the above relationship. [16]

In this study, after assessing different attenuation relationships according to mentioned conditions, four attenuation relationships Ghodrati Amiri et al.[17] Zare et al.[18], Ambraseys et al.[19] and Campbell[20] with the related coefficient of the logic tree 0.4, 0.3, 0.2 and 0.1 are chosen respectively.

As Ghodrati Amiri et al.[17], and Zare et al.[18] relationships are merely for Iran then they are thought over to be more accurate for the calculation of the strong ground motion in Iran.

Ghodrati Amiri et al.[17], attenuation relationship, magnitude and distance parameters have considered directly in the attenuation relationship. Also, bed type effect, fault mechanism, tectonic terms with data classification in different groups and each group modeling have mentioned. Models for Zagros regions and also Alborz and Central Iran in different site conditions for maximum effective acceleration, maximum effective velocity and effective peak acceleration parameters in horizontal and vertical coordination have been obtained. Up to two components are used for horizontal coordination.

Consequently higher weighted coefficient is given to them. But the highest weighted coefficient is given to Ghodrati Amiri et al.[17] because it is recent. Ambraseys et al.[19] which is for the Middle East and, Campbell[20] is for the world and Zare et al[18] is for Iran.

Selection of appropriate attenuation relationship is very important in validity and reliability of the analysis results therefore, there are some important notes that must be paid attention for the selection of attenuation relationship. For determined seismic hazard spectra four attenuation relationships were found from the existing attenuation relationship list to satisfy our demands. The relationships are Ambraseys et al.[19] , Thierry - Berge et al.[21], .Ghodrati et al.[22] and Ghasemi et al.[23] were applied using the logic tree method with weight of 0.2, 0.1, 0.4 and 0.3 In Ambraseys et al.[19], a large set of seismic data pertaining to Europe zone and its vicinity (Middle East) has been used for the development of mentioned equations to calculate maximum horizontal spectral accelerations. For the development of horizontal attenuation relationship, Iranian seismic records including Naghan, Tabbas and Manjil were used which is one of its advantages. In this relationship, the magnitude scale is M, and magnitude range is assumed to be 4<Ms<7.5. The focal depth of 81% of the applied records in this relationship is between 5 and 15 km. The site soil types considered in this relationship are in the form of 4 categories of soil based on the average velocity of shear wave in the depth of 30 meters, similar to the Iranian Code of Practice for Seismic Resistant Design of Buildings[1]. The general form of these horizontal and vertical attenuation relationships is:

$$\text{Log}\, Y = C_1(T) + C_2(T)M_S + C_4(T)Log(r) + C_A S_A + C_S S_S + \sigma p \quad (5)$$

Where:

Y= The maximum spectral acceleration, MS = Surface wave magnitude, r=√(D^2+h^2) in which D is the shortest horizontal distance from site to the epicenter and h is the focal depth, Sa and Ss =Site effects, T=Period, σ =standard deviation.

The values of coefficients: C1 (T), C2 (T), h0, C4 (T), CA, CS, and σ are calculated for periods from 0.1 to 2 sec.

In Thierry - Berge et al.[21] also, a large set of European strong motion records and American records have been used for the development of mentioned equation to calculate maximum horizontal spectral accelerations. For the development of horizontal attenuation relationship, 37 of Iranian seismic records including Tabbas and Manjil were used which is one of its advantages. In this relationship, the magnitude scaleis M, and its range is 4< Ms <7.9. The site soil types considered in this relationship are in the form of 2 categories of soil based on the average velocity of shear wave in the depth of 30 m. The general form of this horizontal attenuation relationship is:

$$\log PSA(f) = a(f)M + b(f)d - Log(d) + C_{1,2}(f) \quad (6)$$

Where:

PSA= The maximum spectral acceleration, M= Surface wave magnitude, d= Hypo central distance, C1 and C2= Site effects and the values of coefficients: a(f) and b(f) are calculated for frequencies a(f) from 0.1 to 34 Hz.

In Ghodrati Amiri et al.[22] attenuation relationship, magnitude and distance parameters have considered directly in the attenuation relationship. Also, bed type effect, fault mechanism, tectonic terms with data classification in different groups and each group modeling have mentioned. Models for Zagros regions and also Alborz and Central Iran in different sit conditions for maximum effective acceleration. The general form of this horizontal attenuation relationship is:

$$\log(SA) = C_1 + C_2 M_S + C_3 Log(R) \quad (7)$$

Where:

SA = spectral acceleration in cm/s2, MS = Surface wave magnitude, C1 and C2 and C3= Site effects and the values of coefficients

In Ghasemi et al[23] attenuation relationship, to classify the recording stations as rock (Vs30 ≥ 760 m/s) and soil (Vs30 < 760 m/s), priority is given to Vs30 and surface geology data, if available. The general form of this attenuation relationship is:

$$\log S_A(T) = a_1 + a_2M + a_3Log(R + a_4 10^{a_5 M}) + a_6S_1 + a_7S_2 \quad (8)$$

Where:

SA(T) is the spectral acceleration with 5% damping in cm/s2, a1–a7 are period-dependent coefficients that must be determined via regression analysis.

The variables S1 and S2 take on values as: S1=1 and S2 = 0 for rock and S1 = 0 and

S2 = 1 for soil.

11. Maximum Seismicity Magnitude Function and Fault Rupture Length

Maximum Seismicity Magnitude Function depends on knowing design spread geological and seismotectonic structure behavior. Generally, this linear experimental function for each region is expressed as below:

$$\log L = a + bM \quad (9)$$

Where, M is maximum expected magnitude and a, b are constant coefficient. L is fault rupture length (that causes earthquake) and in fact, it is a percentage of fault total length.

This percentage is differed for faults with different lengths. Nowroozi[14] show that the percentage generally includes 30 to 100 percent of fault length; for faults greater than 300 km is equal to 30%, whereas for smaller than that is 50% and for minor faults is 100%.

Some researchers like Nowroozi[14] have expressed several relations for defining relationship between fault rupture length and earthquake magnitude. after studying 10 major earthquakes in Iran and investigating active faults ruptures such as Zagros, Northern Alborz, Tabriz, Zomorod in Esfahan, Dehshir in southeastern Esfahan, Shahr babak in Kerman and Darunedasht Biyaz in Makran region, Nowroozi presented the following empirical relation:

$$M_S = 1.259 + 1.244Log(L) \quad (10)$$

Where:

Ms = surface seismicity magnitude and L is the rupture length in meter

12. Logic Tree

Probabilistic calculations allow considering uncertainty values of a specific seismic hazard model parameters systematically. However, in some cases best selection of a seismic hazard models components may be unclear itself. Logic Tree provides appropriate framework for comprehensive behavior of an uncertainty model (Coppersmith and Youngs[24], Kulkarni et al.[25] Power et al[26]).

Logic Tree method allows using different models. In this method, a weight coefficient is specialized to each of them and is used as a relative probability to modify the model. The model is formed by a node series (which model is determined in them) and a branch series (that determine different models in node). Probabilistic summation of all branches end to a group must be 1. Logic Tree allows to consider uncertainty in selection of attenuation, size distribution and maximum seismicity magnitude models. Fig. 3 shows used Logic Tree in which uncertainty is mentioned in attenuation relationships and seismicity parameters. The reason why four attenuation relationships are used instead of one relation in this paper is that Iran's data do not have the required accuracy. In another word, attenuation relationship like Campbell[20] is a worldwide relation which data for other countries are used in this relation, and the accuracy is considerable.

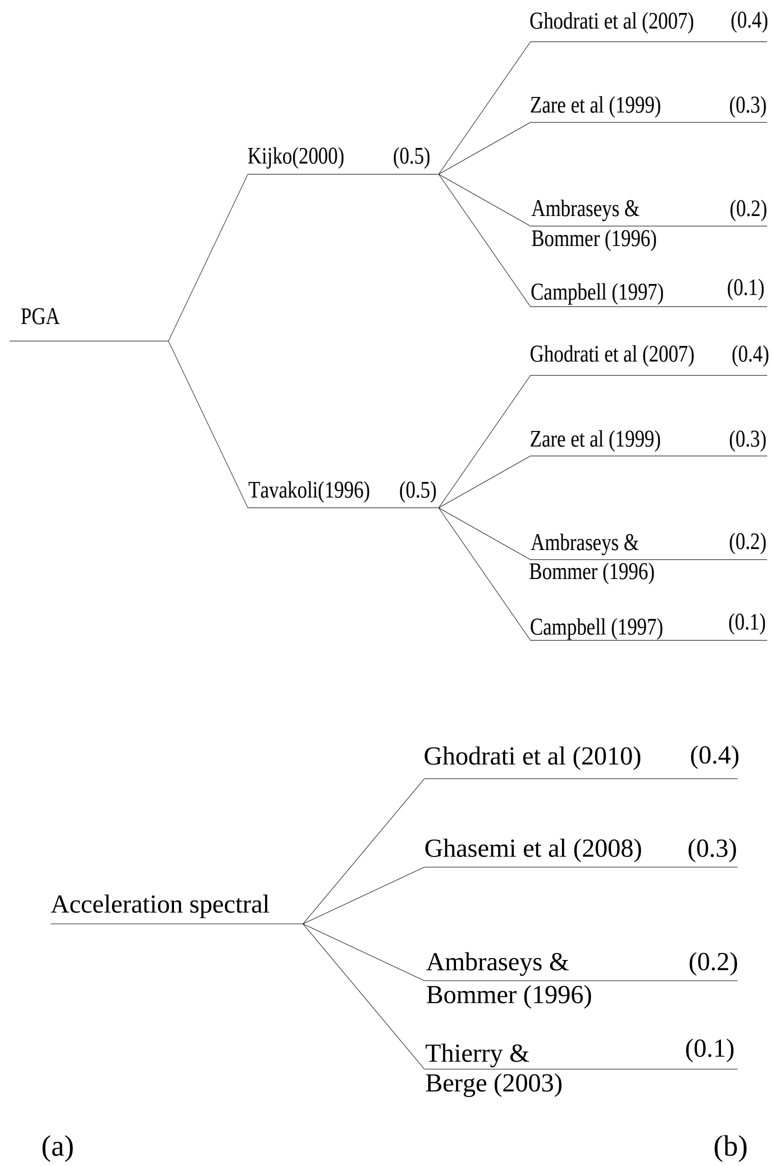


Fig. 3. Logic Tree: (a) PGA, (b) Sa

Seismicity parameters based on Tavakoli[13] that were calculated for Iran's earthquake states, are used in this study to compensate seismic data's inaccuracy; this was done for a region with 200 km-radius of Esfahan. On the other hand, time range that Tavakoli used in his seismicity parameters study is restricted to the time interval of 1922 to 1995, but in this study, time range for finding and calculating seismicity parameters is started from 4 B.C. to 2007; this range improves Tavakoli's time range limit. With respect to advantages and disadvantages of each method, it is obvious that two methods applications in calculations and using in Logic Tree are very useful.

13.Probabilistic Seismic Hazard Analysis

In this Section based on seismicity sources modeling, using obtained seismicity parameters and SEISRlSK III [15] software, Peak Ground Acceleration is estimated during useful life of structure. The reason why SEISRlSK III [15] is used as the hazard analysis software instead of current advanced software is that this software is sufficient and proper for the research because of data and exist information from previous related researches in the studied region and also incompleteness and low accuracy of recorded data and due to lack of a dense seismography network. Generally strong ground motion values for different hazard levels (different invasion probability) are considered in probabilistic seismic hazard analysis. Two levels of hazard that are mentioned in this study are: 2% and 10%, probabilities of exceedance in 50 years. In this study the whole area of interest was subdivided into a grid of 13 × 11, totally 143 sites, with 1 km space between horizontal and vertical points. After grid, hazard analysis calculations in 2 levels (as mentioned before) were implemented. Peak Ground Acceleration maps for the considered grid are shown in Fig. 4.

For the seismic hazard probabilistic evaluation, the software SEISRlSK III [15] was utilized to calculate the maximum spectral acceleration in the structure lifetime. The calculated values can be shown in the form of iso-acceleration lines for each period with a specific hazard level in the structure lifetime.

In probabilistic seismic hazard analysis, the strong ground motion values are generally considered for different seismic hazard levels (different PE). In this study, based on the Seismic rehabilitation code for existing buildings in Iran (IIEES) [27], 2 hazard levels were considered:

-Hazard level 1: This hazard level is based on 10% PE in 50 years which is equivalent to the return period of 475 years. Earthquake with this hazard level is called Design Basis Earthquake (DBE) in Iranian Code of Practice for Seismic Resistant Design of Buildings (BHRC) [1].

-Hazard level 2: This hazard level is based on 2% PE in 50 years which is equivalent to the return period of 2475 years. Earthquake with this hazard level is called Maximum Probable Earthquake (MPE).

Before the calculations, a grid of sites must be considered in the region where seismic hazard analysis will be performed. For this purpose a grid of 4x5 or 20 sites shall be considered. The longitude distance of these sites to each other is 2.2 km and the latitude distance is 1.8 km. Seismic hazard analysis shall be performed for each of these sites.

As a result, our outputs are maximum horizontal spectral acceleration with 2% and 10% PE in 50 years lifetime of structure considering the mentioned periods. Some instead of Instances of horizontal accelerations are presented in Figs. 5 to 6.

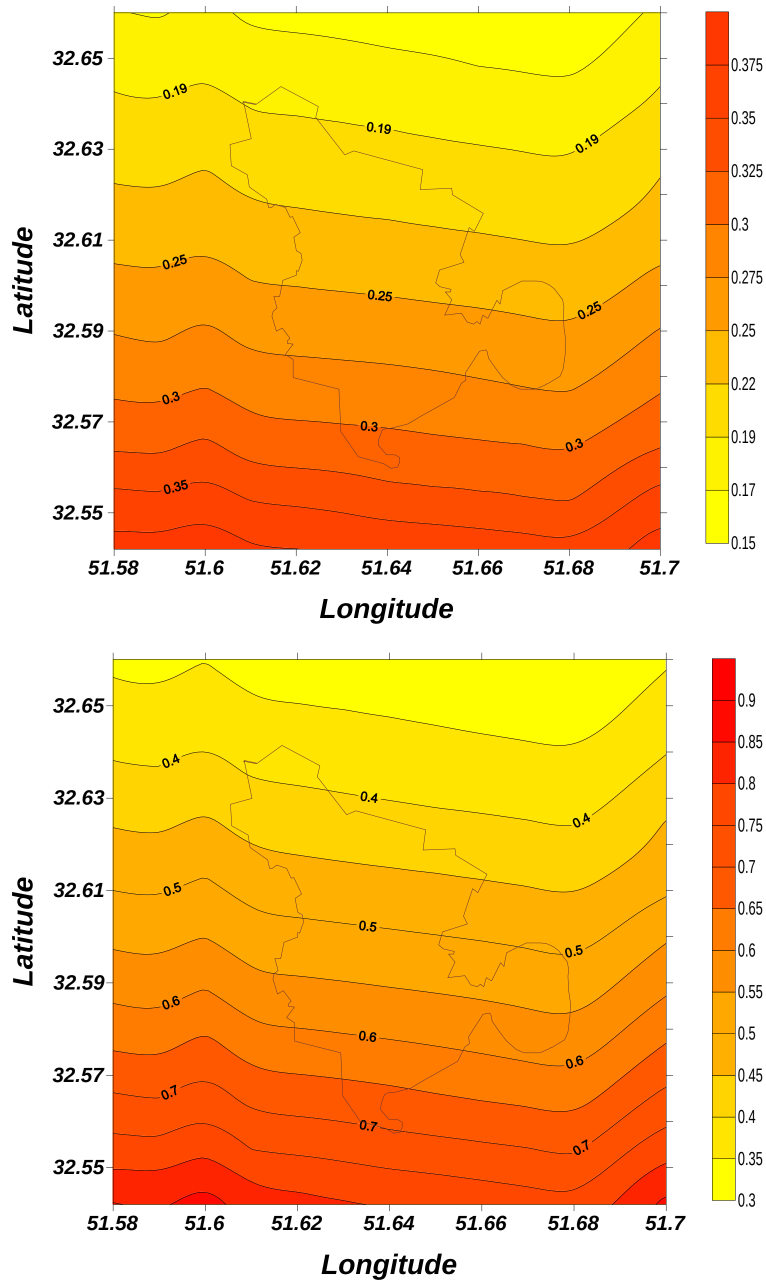


Fig. 4. Final seismic zoning map (PGA over bedrock) of Esfahan (up) 475 year return period, (down) 2475 year return

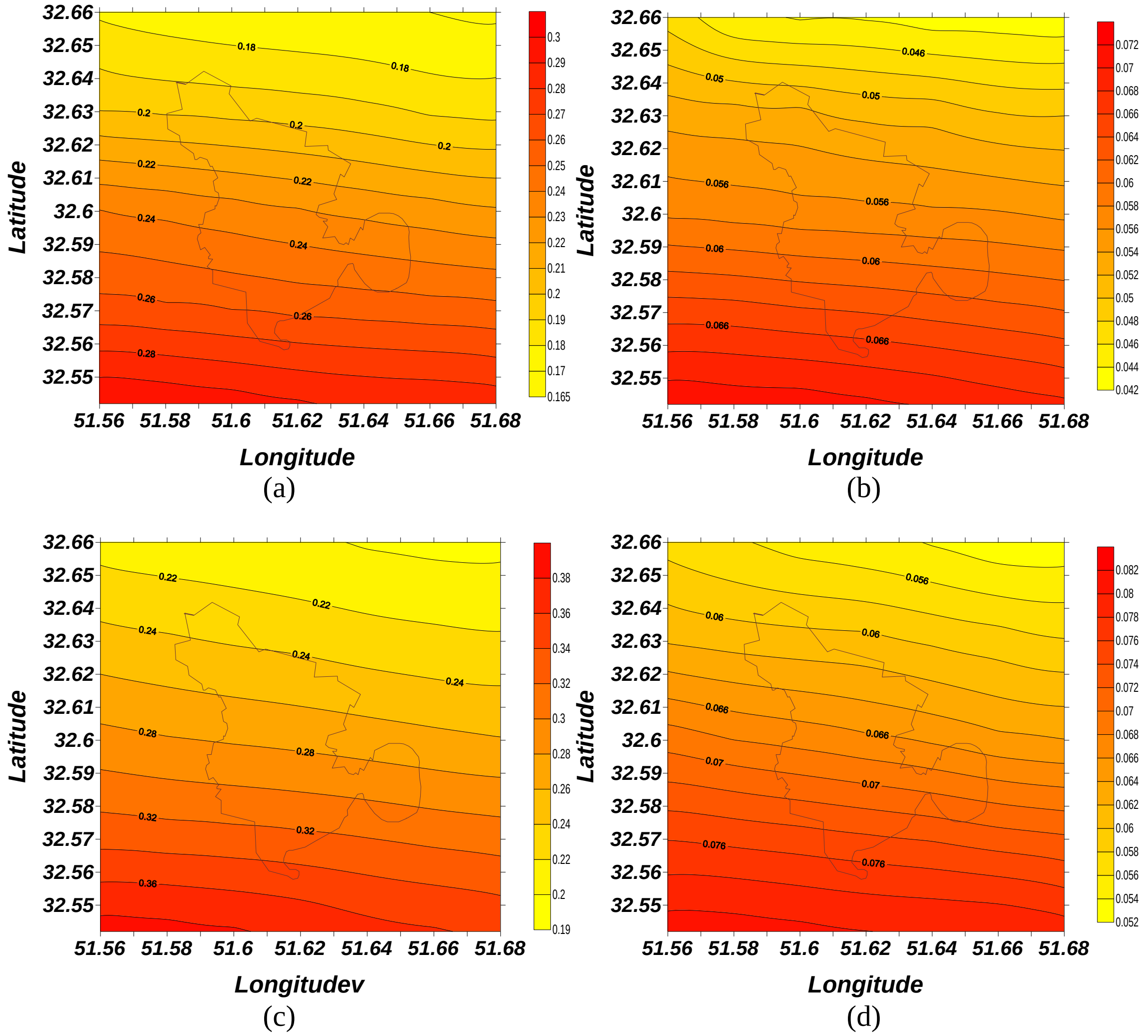
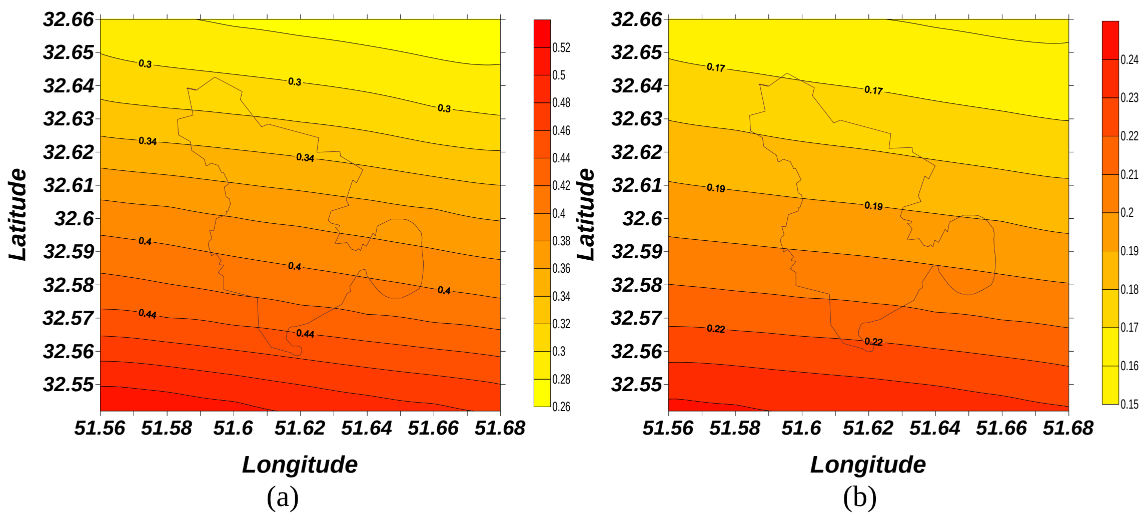
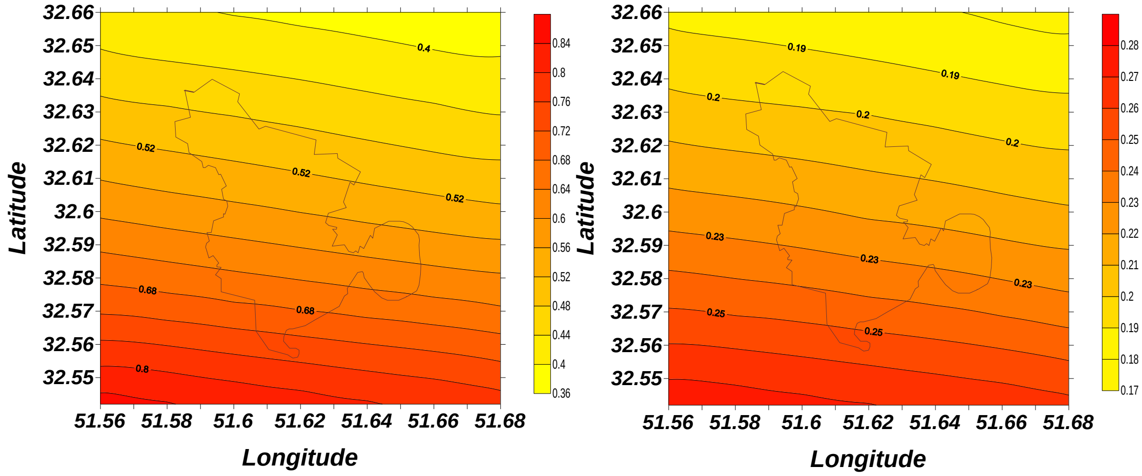


Fig. 5. Horizontal spectral acceleration (g) with 10% Probability of Exceddence in 50 years for Esfahan: (a) 0.2 sec, Rock, (b) 1.0 sec, Rock, (c) 0.2 sec, Soil, (d) 1.0 sec, Soil.





(c) (d)

Fig. 6. Horizontal spectral acceleration (g) with 2% Probability of Excedence in 50 years for Esfahan: (a) 0.2 sec, Rock, (b) 1.0 sec, Rock, (c) 0.2 sec, Soil, (d) 1.0 sec, Soil.

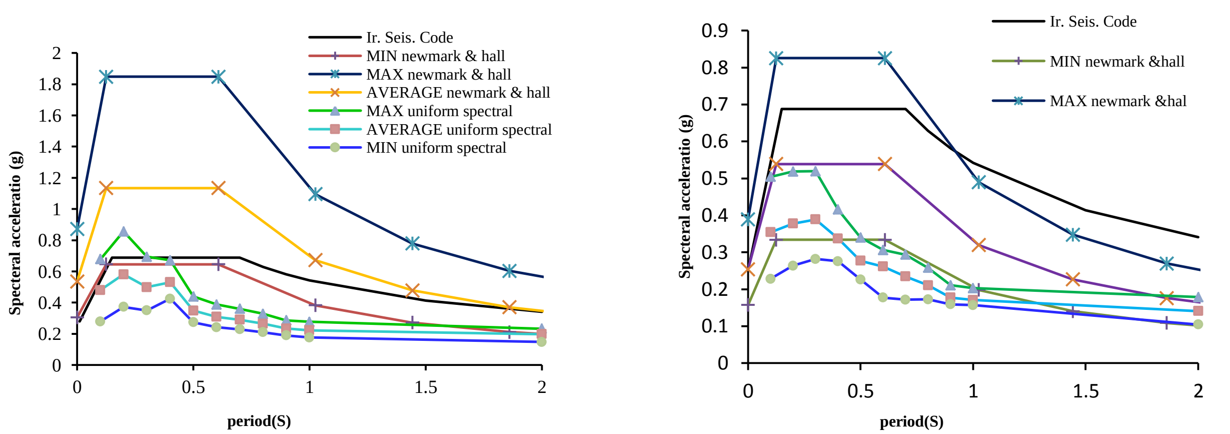
Iranian Code of Practice for Seismic Resistant Design of (BHRC) [1] Buildings uses the equation below for obtaining horizontal spectral acceleration (Sa) with 10% PE in 50 years lifetime of structure considering the mentioned periods:

$$S_a = A.\mathrm{B} \quad (11)$$

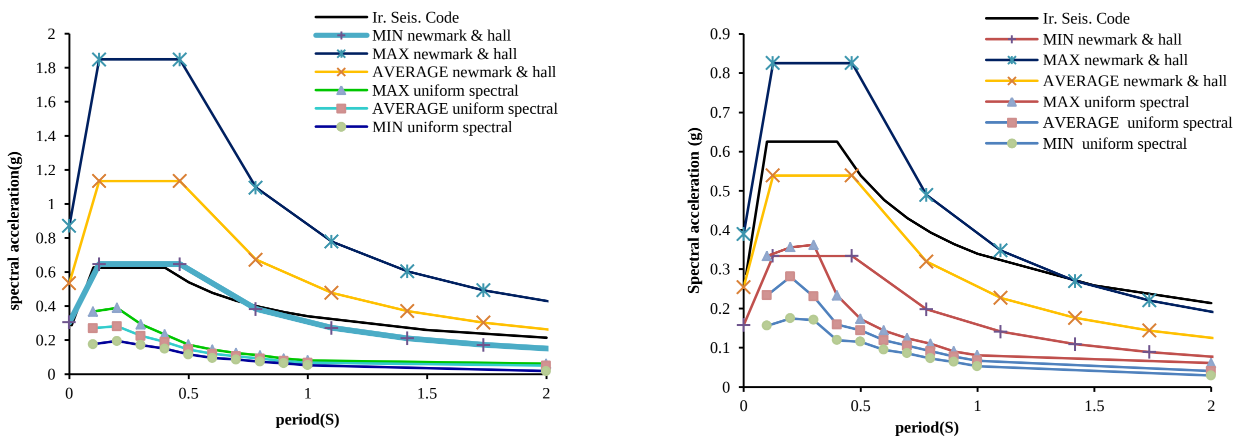
Where:

A the design basis acceleration over bedrock (a suggested value for that is A = 0.25 g for the entire Esfahan region), B the response factor calculated by the simultaneous consideration of the amplifying effects of soil deposit and the structural response with respect to earthquake accelerogram.

Therefor in all the steps, the spectra were calculated for 2 types of soil and rock appropriate to Iranian Code of Practice for Seismic Resistant Design of Buildings (BHRC) [1] for 2 levels of hazard 1 and 2. Maximum, minimum and average uniform hazard spectra were finally presented for comparison with maximum, minimum and average Newmark and Hall[28] hazard spectra.



(a) (b)



(c) (d)

Fig. 6. Uniform hazard spectra, (a) MPE-Soil, (b) EDB-Soil, (c) MPE- Rock, (d) EDB-Rock.

14.Conclusions

In this study, probabilistic seismic hazard evaluation was performed on a grid of 13*11 points in of Esfahan using SEISRISK III [15]. The corresponding results have been depicted by horizontal spectral acceleration maps with 2% and 10% PE (Probability of Exceedence) in 50 years By paying attention to the uniform hazard spectra curves for different periods, it can be noticed that whenever soil type changes from rocky to stiff there is an increase in the spectral acceleration in that region. However in western south parts of Esfahan, due to approaching to the daran Faults and also being situated over small or large faults of the region, there will be higher spectral accelerations than other points.

In the study, in hazard analysis, it is supposed that bed rock is an ideal petrified bed rock and soil conditions and position is not mentioned. Range of PGA variation in this area is 0.18g to 0.31g for 475 years of return period, 0.35g to 0.7g for 2475 years of return period. These results were compared to the results of previous studies and indicated to be justifiable and acceptable.

With PGA maps, it is possible to mention how PGA changes are in the studied region; also, it shows that these changes increase from North to South of the region and are in their peak value in Southwest of the region.

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