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# Peak Ground Acceleration on Bedrock (PGA) and Uniform Seismic Hazard Spectra (UHS) for Different Regions of Kashan, Iran

**Mohammad Javad Ghasemi Dastjerdi, Seyed Ali Razavian Amrei, Gholamreza Ghodrati Amiri**

***Abstract:*** ***The present paper was done under the title of peak ground acceleration (PGA) on bedrock and uniform seismic hazard spectra (UHS) for different regions of Kashan city in two hazard levels. A set of seismic sources, historical and instrumental seismicity data of International Institute of Earthquake authoritative books and websites has been collected, which covers the period of the forth century BC until now. Kijko[2000] method has been applied for estimating the seismic parameters considering lack of suitable seismic data, inaccuracy of the available information and uncertainty of magnitude in different periods. The calculations were performed by using the logic tree method. Five weighted attenuation relations were used ;including Ghodrati et al (2007), 0.3, Akkar & Bommer (2010),0.2, Ambraseys et al (1996),0.2, Campbell-Bozorgnia (2000),0.15 and Campbell-Bozorgnia (2009) ,0.15. Meanwhile in order to determine the seismic spectra based on weighted attenuation spectral relations, and also for the reason of being spectral and more suitable with the conditions of the zone, Ambraseys et al (1996), 0.3, Ghodrati Amiri et al (2010), 0.3, Campbell (1997), 0.2 and Berge-Thierry et al (2003),0.2 were used. The SEISRISK III (1987) software was used to calculate the earthquake hazard. The results of this analysis were submitted including the spectra and maps for 10% and 2% PE in 50 years.***

***Keywords:*** ***Seismic hazard analysis, Peak ground acceleration (PGA), Uniform seismic hazard spectra (UHS), Uniform spectra, Attenuation relationships and Kashan.***

## I. INTRODUCTION

Kashan city,the center of Kashan county with the area about 45 sq. km is located in the northwest of Isfahan province, on the way from Tehran to Ardestan, 33 degrees, 59 minutes, 30 seconds north width and 51 degrees, 27 minutes, east longitude relative to Greenwich meridian and height of 590 meters above sea level. This county is limited to Semnan and Qom provinces in the north, Qom and Central provinces in the west, Ardestan county in the east and Borkhar, Meymeh and Natanz counties in the south. [1] Kashan due to overpopulation, many monuments and plenty of nearby active faults is very important from seismic studies and more importantly earthquake risk analysis point of views. Probabilistic analysis is one of the modern methods in analyzing seismic risk. In this analysis, the uncertainty within different parameters is taken into account and results are presented logically. [1]

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*****Correspondence Author(s)
**Mohammad Javad Ghasemi Dastjerdi**, Department of Civil Engineering, Shahrekord Branch, Islamic Azad University, Shahrekord, Iran.
**Seyed Ali Razavian Amrei**, Department of Civil Engineering, Payame Noor University, Tehran, Iran.
**Gholamreza Ghodrati Amiri**, Center of Excellence for Fundamental Studies in Structural Engineering, School of Civil Engineering Iran, University of Science & Technology, Tehran, Iran.



## II. SEISMOTECTONICS

Numerous active faults threatens Kashan region. This study is done for Kashan within a radius of 200 km from the center of the city. In this region more than 50 faults were identified, the most important and effective faults are shown in table 1. [2]

**Table 1: Major Faults in a Radius of 200 km from the City Center**

| No. | Name |
|---|---|
| | |
| 1 | Zefreh-Kashan |
| 2 | Qom south |
| 3 | Ravand |
| 4 | Kooshk Nosrat |
| 5 | Bidhend |
| 6 | Tafresh |
| 7 | Alborz |
| 8 | Daran |

Some of the existing faults in the studied region are shown in figures 1 and 2.

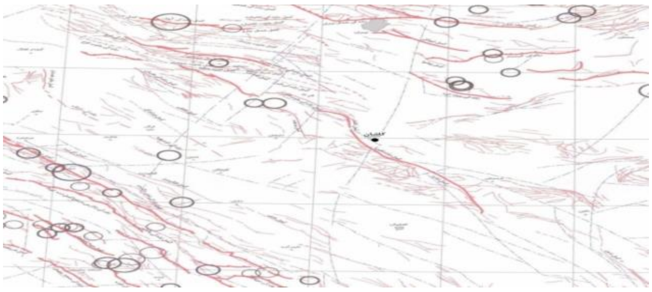

**Figure 1: Existing Faults in the Studied Region [2]**

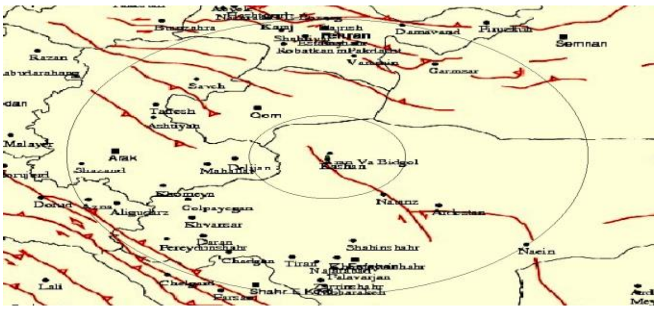

**Figure 2: Existing Faults in the Studied Region [2]**


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## III. THE PEAK EARTHQUAKE MAGNITUDE AND FAULT RUPTURE LENGTH APPENDIX

To estimate the relationship between the peak expected magnitude and fault length, the seism tectonic and geotectonic behaviors of the concerned area were taken into consideration and the following relationship was obtained:

Ms = 1.259 + 1.244logL (1)

Where in equation (1), Ms is the surface magnitude and L is the probable length of the fault rupture in meters. [3]

## IV. SEISMICITY

The history of past earthquakes in each width is an indication of the Seismicity of that area. Thus, in order to conceive the Seismicity features, we should have a comprehensive list of occurred earthquakes in the area. In the present work, a number of earthquakes within a radius of 200 km from center of Kashan city were collected and considered. [1]

### A. Historical Earthquakes:

The historical earthquakes are those earthquakes occurred before twentieth century (before 1900 AD). As far as the seismic networks had not been developed at that time, the collected information from old and historical books and sometimes oral speech was concerned, so their validity may be under question because they may have exaggerated the extent of the damage and destruction in excess negligence. However, the existence of such places could be important in the process of gathering information. The most important historical earthquakes in Kashan region are mentioned in table 2. [4]

**Table 2: Historical Earthquakes Occurred in the Studied Area based on Ambraseys and Melville's Book 1982 [4]**

| Magnitude | Longitude | Latitude | Date |
|---|---|---|---|
| **7.6** | 51.8 | 35.5 | -400 |
| **7.2** | 52.2 | 35.3 | 743 |
| **7.1** | 51.5 | 35.6 | 855 |
| **5.3** | 51.0 | 35.7 | 864 |
| **7.2** | 50.7 | 35.7 | 1177 |
| **6.2** | 49.4 | 33.5 | 1316 |
| **5.7** | 52.3 | 32.9 | 1344 |
| **5.9** | 50.0 | 34.5 | 1495 |

### B. Instrumental Earthquakes:

In spite of the uncertainties in estimating the epicenter, focal depth, and magnitude of earthquakes in seismic data in twentieth century, these earthquakes are crucial with regard to the instrumental registration. From 1963, with the installation of seismography network, the uncertainties in their estimations were prominently decreased. A list of instrumental earthquakes in Kashan from 1900 up to now has been collected from different resources, the most important of which is the international research institute of seismological and earthquake engineering research website. [2]

**Table 3: Instrumental Earthquakes Occurred in the Studied Area [2]**

| Magnitude | Longitude | Latitude | Date |
|---|---|---|---|
| **6.5** | 52.1 | 35.7 | 1665 |
| **5.9** | 51.4 | 34.0 | 1755 |
| **6.2** | 51.3 | 34.0 | 1778 |
| **6.4** | 51.4 | 33.6 | 1844 |
| **5.5** | 50.3 | 32.6 | 1853 |
| **6.4** | 52.5 | 34.9 | 1868 |
| **5.8** | 49.7 | 33.1 | 1876 |

### C. Earthquake Magnitude:

In the present study, the surface-wave magnitude, Ms, was used in order to analyze the seismic hazard magnitude. As far as, the collected magnitudes were not of Ms type, they were converted to Ms. In order to convert ML to Ms, the table 4 adapted from Nutti 1993 and Krinitzsky 1987 was employed. However for the data not available in the table, the linear interpolation was used. [1]

**Table 4: Converting ML to Ms [1]**

| ML | MS |
|---|---|
| **4.3** | **3** |
| **4.8** | **3.6** |
| **5** | **4** |
| **5.3** | **4.6** |
| **5.8** | **5.6** |
| **6.3** | **6.6** |
| **6.8** | **7.3** |
| **7.3** | **8.2** |

Considering the interpolation between ML and Ms and with regard to the point that for probabilistic risk analysis, the earthquakes with magnitudes more than 4 (Ms≥4.0) are considered, all earthquakes with ML <5.0 were removed from Kashan earthquake catalog. Moreover to convert mb to Ms, the relationship of Committee on Iranian Large Dams, Ms = 1.21mb - 1.29 was applied. [5] And finally for converting Mw to Ms the following two modes were followed:

If Mw<6.0, then Mw=mb

If Mw>6.0, then Mw = Ms

Where, Ms and mb stand for the surface-wave magnitude and the body-wave magnitude respectively. [1]

## V. SEISMICITY PARAMETERS OF KASHAN

Seismicity parameters or the peak expected magnitude, Mmax, λ, and β are among the basics of the seismicity of a place. They are used to indicate the seismicity of a place. After collecting the earthquake data for Kashan, due to the fundamental assumption in estimating the seismicity parameters, i.e. independence of the earthquakes from each other, the variable windowing method in time and space domains Gardner and Knopoff was used for elimination of foreshocks and aftershocks from the earthquake events list. [6]


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### A. Determination of SeismicityParameters

In this paper, in order to estimate the seismic parameters due to the shortage of appropriate seismic data, the low accuracy of the available information and uncertainty of earthquake magnitudes in different periods, the Kijko method [7] was used based on the probabilistic method of peak likelihood estimation. In this method, with regard to the faults and the low accuracy of seismic data at different times, their occurrences are used in determination of seismicity parameters, Mmax, λ, and β. Estimation of the parameters is as follows: [1]

1. At first, a detailed database of historical and instrumental earthquakes in the studied area was prepared. For this purpose, the Ambraseys -Melville book for historical earthquakes, as well as the international institute of earthquake website for instrumental earthquakes were used to obtain information.
2. Converting the prepared magnitudes to surface wave magnitudes (using the relationship and the table mentioned before)
3. Determination of the minimum damaging magnitude and eliminating the magnitudes less than that (Ms<=4 Richter).
4. Removing the foreshocks and aftershocks using the Knopoff software.
5. Calculation the Kijko seismicity parameters (Mmax-Lambda-Beta).

The results of applying this method includes determination of the seismic parameters shown in table 5.The return period is probability of event and the magnitude of seismic events at different times. In Figure 3, estimation of the return period of earthquakes in Kashan by Kijko method is presented. [7]

**Table 5: Values of Seismic Parameters in the Studied Area (Kijko Method) [7]**

| Result | | |
|---|---|---|
| Beta | 1.68 ±0.01 | b=0.73 ±0.01 |
| Lambda | 1.56 ±0.24 | for M min= 3.00 |
| Mmax | 8.10 ±0.71( for SIG( X max )= 0.50 | |

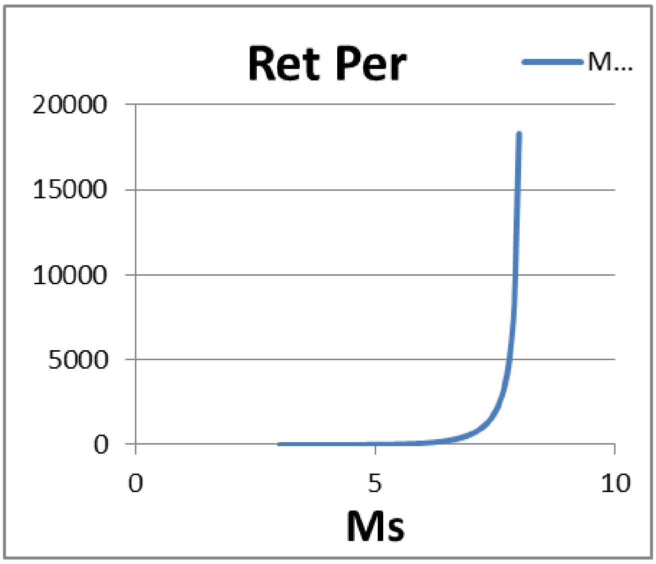


**Figure 3: Estimation of the Return Period of Earthquakes in Kashnn (Kijko Method)**

## VI. Seismic Hazard Analysis

The present paper aims at providing Peak Ground Acceleration (PGA) on bedrock and uniform seismic hazard spectra (UHS) using Probabilistic Seismic Hazard Analysis. In this method, the procedure includes: identifying and modeling the seismic sources, applying the probability distribution of their possible failures, estimation the seismic power of the springs, examining the seismicity or time distribution of the occurred earthquakes which concludes the recurrence relationship(Recurrence-Magnitude), evaluation of local site effects such as soil types, evaluation and choosing an appropriate attenuation relationship for peak ground acceleration, calculation of the parameters of strong ground movement for designing taking into account the possible uncertainty and finally preparation of uniform acceleration maps and spectrum drawing.

### A. Attenuation Relationship:

The selection of an appropriate attenuation relationship is of high importance in the reliability of the results taken from seismic hazard assessment. Throughout this process, the following points are to be taken into consideration: belonging to the same region , type of magnitude unit, magnitude range, distance range, how the faults ruptured, variety of soil types, types of rocks, etc. Knowing about just above mentioned points, here are five different attenuation relationship, Ghodrati et al (2007) [8], Akkar & Bommer (2010) [9], Ambraseys et al (1996)[10] , Campbell (2000)[11] and Campbell (2009)[12] used in the process of providing Peak Ground Acceleration (PGA) on bedrock and uniform seismic hazard spectra (UHS) through the logic-tree method with the weighs of 0.3, 0.2, 0.2,0.15 and 0.15 respectively. Moreover, in order to provide spectra acceleration map and uniform seismic hazard spectra through logic-tree method, Ambraseys et al (1996) [10], Ghodrati Amiri et al (2010) [13], Change- Campbell (1997) [14] and Berge-Thierry (2003) [15] are combined with the weighs of 0.3, 0.3, 0.2and 0.2 respectively. The reason for using the Logic-tree method is that using a single attenuation relationship is not an appropriate choice because the certainty of the given data is not as reliable as desired. Moreover, the regional and global relationships which enjoy a higher accuracy in comparison with those of Iran, the other countries' data are used in the provision of their model. Therefore, as a logical conclusion, the best method is the simultaneously use of both different attenuation relationships together with the Logic-tree. Performing in this way, each one compensate for the other one's shortage. There are two parameters in assigning the weigh to the branches of each Logic-tree, including conditions in the given site and considering higher effect of regional relationship. In Table 6 and 7 the used Logic-trees with the weight of each branch are indicated.

**Table 6: The used Logic-Tree Together with Weight of each Category for Determination of PGA**

| Ghodrati et al (2007) | 0.3 |
|---|---|


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| | |
|---|---|
| **Akkar&Bommer(2010)** | 0.2 |
| **Ambraseys et al (1996)** | 0.2 |
| **Campbell (2000)** | 0.15 |
| **Campbell (2008)** | 0.15 |

**Table 7: The used Logic-Tree Together with Weight of each Category for Determination of UHS**

| | |
|---|---|
| **Ghodrati et al (2010)** | **0.3** |
| **Ambraseys et al (1996)** | 0.3 |
| **Campbell(1997)** | 0.2 |
| **Berge-Thierry (2003)** | 0.2 |

### B. Probabilistic Seismic Hazard Analysis:

In this part, based on the modeled seismic sources, seismic parameters, and SEISRISKIII software [16], the peak horizontal acceleration on bedrock (PGA) and horizontal spectral acceleration, each with 10% and 2% PE in 50 years (equivalent to a return period of 475 and 2475 years) were estimated in accordance with the levels of 1 and 2 of Seismic Rehabilitation of Existing Building [17], for a 19x11 network where surrounds Kashan appropriately. The calculations were done for soil type 3 based on Iranian Code of Practice for Seismic Resistant Design of Buildings (Standard 2800) [18]. The maps for peak ground acceleration on bedrock (PGA) are shown in Figure 4 and horizontal spectral acceleration based upon the soil type 3 of Kashan city for 0.1, 0.3, 0.5, 1 and 2 seconds periods are presented in Figures 5 to 9. [1]

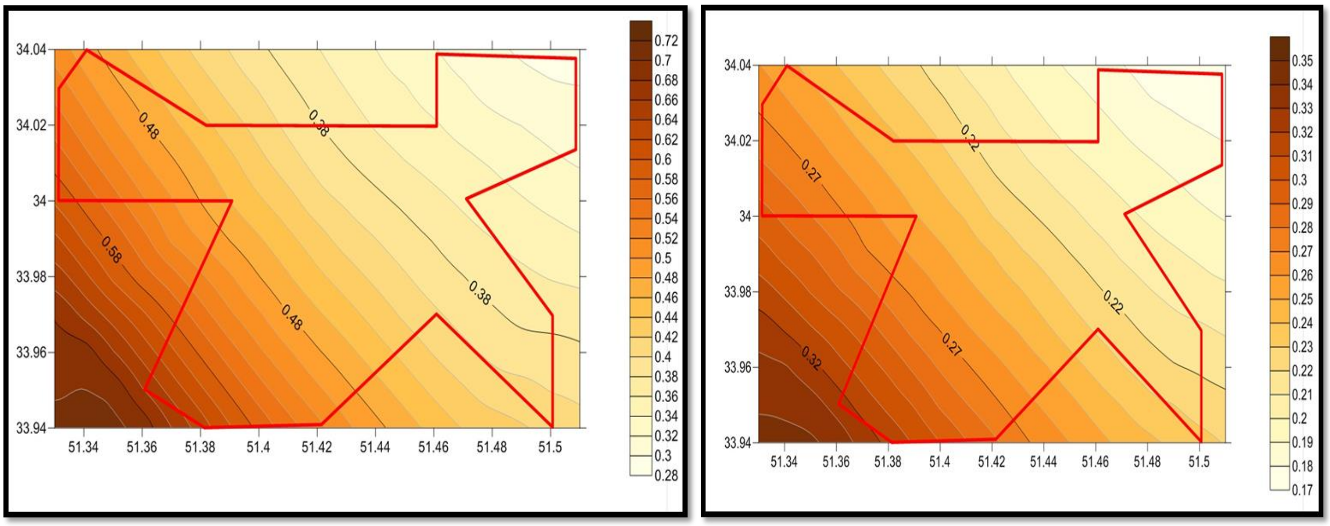


**Figure 4: Zoning Maps of PGA with 10% and 2% PE (probability of event) in 50 years (Right to Left) in Kashan**

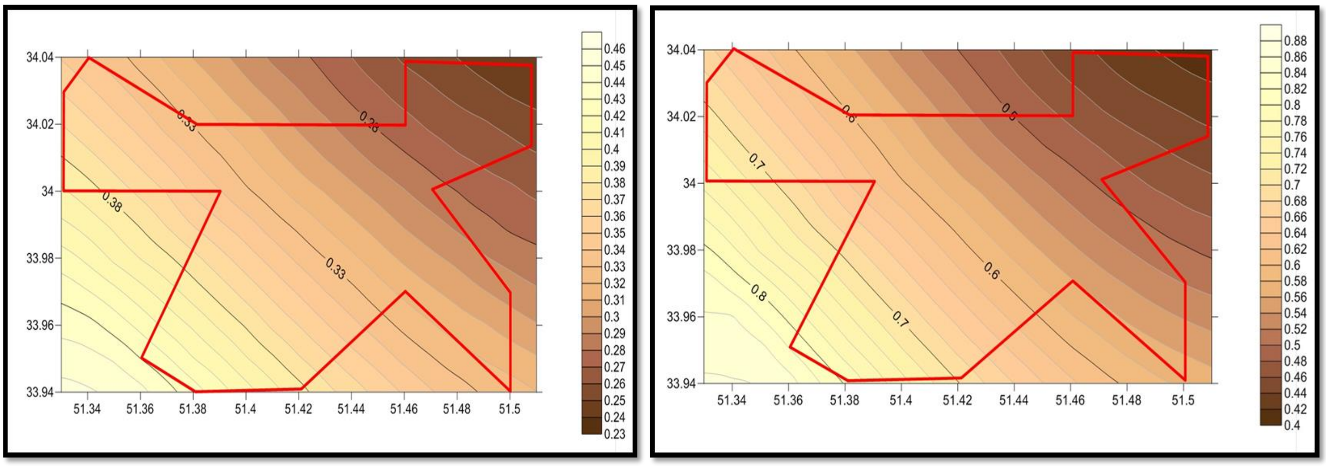


**Figure 5: Zoning Maps of 0.1 s Spectral Acceleration with 10% and 2% PE in 50 Years (Right to Left) in Kashan**



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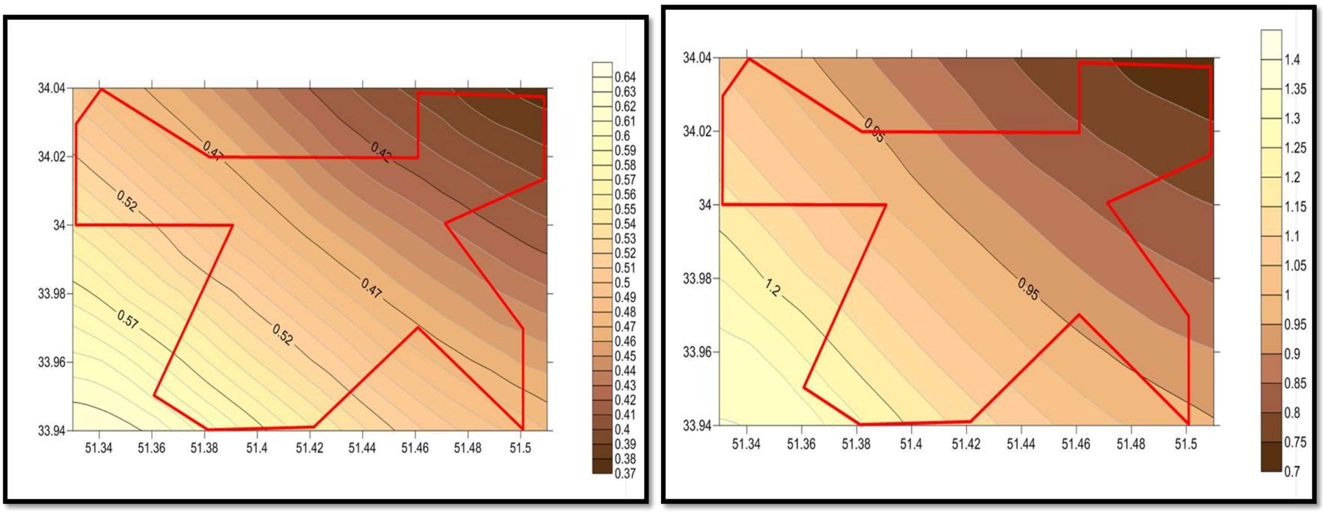


Figure 6: Zoning Maps of 0.3 s Spectral Acceleration with 10% and 2% PE in 50 Years (Right to Left) in Kashan

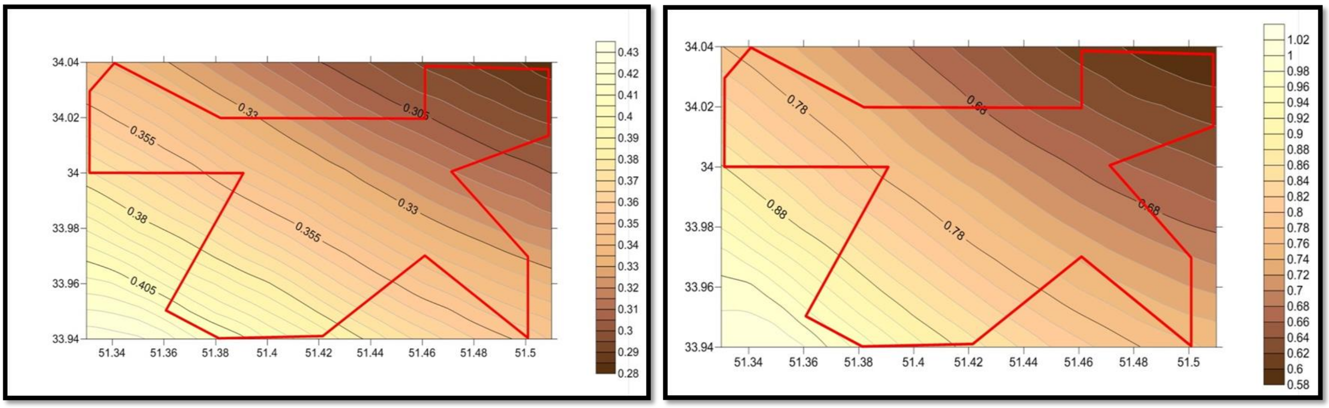


Figure 7: Zoning Maps of 0.5 s Spectral Acceleration with 10% and 2% PE in 50 years (Right to Left) in Kashan

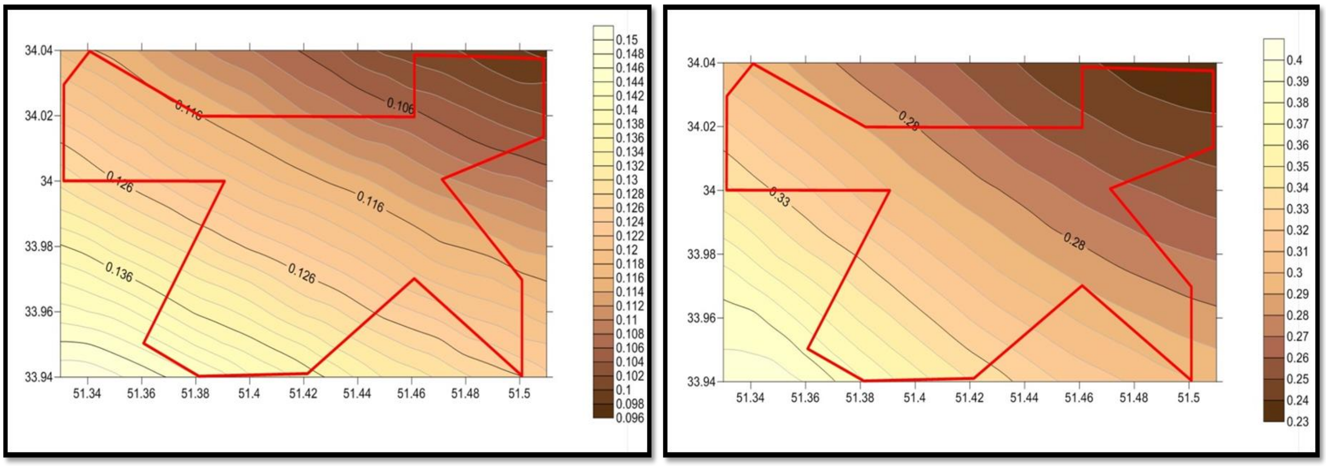


Figure 8: Zoning Maps of 1.0 s Spectral Acceleration with 10% and 2% PE in 50 years (Right to Left) in Kashan


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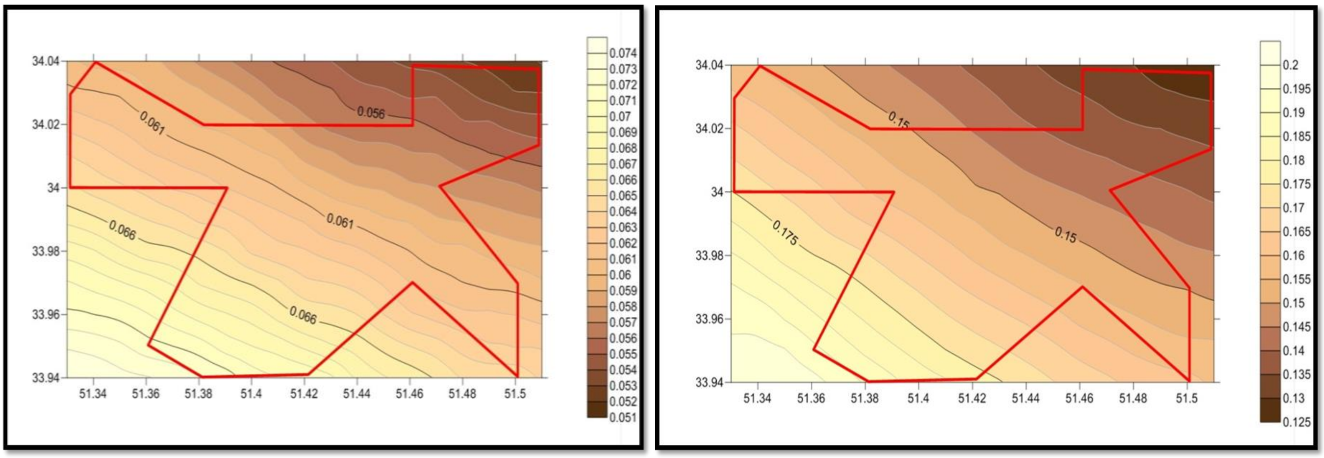


**Figure 9: Zoning Maps of 2.0 s Spectral Acceleration with 10% and 2% PE in 50 years (Right to Left) in Kashan**

## VII. Uniform Hazard Spectra (UHS)

1) As the name implies, a uniform hazard spectrum (UHS) is formed as a response spectrum, related to spectrum lengths which all have the same probability of occurrence. Since the PGA is indicative of the acceleration of a rigid body (T=0), it does not meet our requirements for the design of structures with various periods (especially for structures with high periods). Therefore the spectral maps are needed for a more detailed study of the structural behavior and codification of the designing regulations.
2) So recently in the United States and Canada, and a limited number of countries these maps are formed and their uses in designing regulations are under consideration, so that a trial application in NEHRP Regulations is being investigated recently.
3) In Figures 10 and 11, the uniform hazard spectra for the soil type 3 is presented based on Seismic Rehabilitation of Existing Building for Kashan city. The spectra in these figures are presented as the peak, minimum and average values of spectral acceleration at different points in the range of the network. Furthermore for comparison, in risk level 1,the standard spectra based on Iranian Code of Practice for Seismic Resistant Design of Buildings (Standard 2800) [18] and 70% of the standard value and in risk level 2, the standard spectra of Iranian Code of Practice for Seismic Resistant Design of Buildings (Standard 2800) [18] and 150% of the standard value are presented.

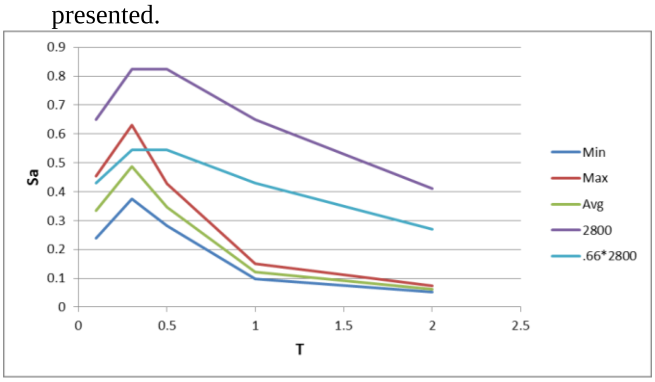


**Figure 10: UHS (Up to Down) for Soil Type 3, with 10% PE in 50 years useful Life of the Structures in Kashan**

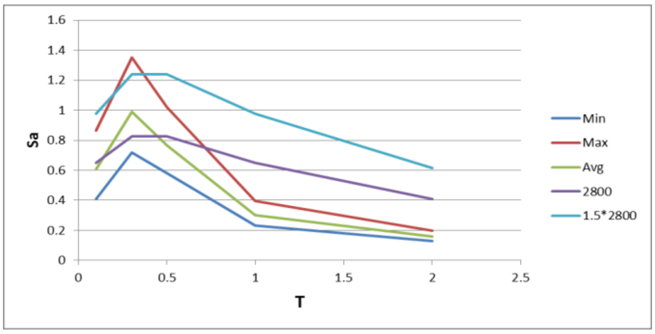


**Figure 11: UHS (Up to Down) for Soil Type 3, with 2% PE in 50 years useful Life of the Structures in Kashan**

## VIII. Conclusions

1- PGA event with a probability of 10% in 50 years (return period of 475 years or risk level 1of seismic rehabilitation instruction of the existing buildings) in Kashan varies from 0.17g to 0.31g, which has been mentioned to be 0.3 in Iranian Code of Practice for Seismic Resistant Design of Buildings (Standard 2800). The 0.31g value is obtained in the most western point of the south of the city which is very close to Zefreh-Kashan fault, but in the other points it does not exceed from 0.3g.

2- PGA event with a probability of 2% in 50 years (return period of 2475 years or risk level 2 of seismic rehabilitation instruction of the existing buildings) in Kashan varies from 0.28g to 0.61g.

3- By observing the uniform hazard spectra, we conclude that the horizontal spectral acceleration comprises the highest values in the period of 0.3 seconds for both 2% and 10% probabilities of event, so that we observe an increment in spectral acceleration till the period of 0.3 seconds, and then a gradual decrease in spectral acceleration can be seen. This subject can be seen as well in Iranian Code of Practice for Seismic Resistant Design of Buildings (Standard 2800).

4- For preparing the maps of spectral acceleration and specially the uniform hazard spectra. The need for a constant risk is needed, which in this project the hazard risks in two levels 1 and 2 with 2% and 10% probabilities of event in 50 years useful life of the structures were adopted. Thus, in each period of this spectra, the level of seismic hazard is the same and fixed.

In designing, this is a great help to the designer in


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various risk levels. Therefore the designer in any location of the studied area and with any required period and with specific level of seismic hazard can identify the horizontal spectral acceleration by the use of these uniform risk spectrums.

5- In general, the west, and particularly the southwest of the city of Kashan has more spectral acceleration and spectral acceleration of the east and northeast of the town is less. This difference is due to the passage of the Kashan – Zefreh and Ravand(Fin) faults from west of kashan. So we can say that the west and the south west of the town are more dangerous relative to the east and northeast of the town. This rule is valid in all periods.

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