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UNIFORM HAZARD SPECTRA FOR THE IRANIAN CITY OF SHIRAZ

G. Ghodrati Amiri[1*], S.A. Razavian Amrei[2] and H. Alaei[3]
[1]Center of Excellence for Fundamental Studies in Structural Engineering, College of Civil Engineering, Iran University of Science & Technology, Tehran, Iran
[2]Department of Civil Engineering, Payame Noor University, Tehran, Iran
[3]Department of Civil Engineering, Qaemshahr Branch, Islamic Azad University, Qaemshahr, Iran

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ABSTRACT

In this study, uniform hazard spectra assessment is performed for the city of Shiraz and eight graphs are prepared to indicate the probabilistic estimate of spectral ordinates over bedrock in this area. For this assessment; first, earthquake catalogue and main active faults in a radius of 200 km are gathered and processed and then seismicity parameters are obtained by Kijko and Tavakoli methods, after that the results are introduced to the computer program of seismic hazard analysis "SEISRISK III" by three attenuation relationships and eventually the outputs are combined by logic tree method. The isospectrums are calculated in two levels of hazard in four soil types; which are needed for retrofit of building in Seismic Rehabilitation Code for Existing Buildings in Iran. The Results show that the recommended SA and what is achieved in this study for the return periods of 475 and 2475 years, are same together in maximum and mean amounts, respectively.

Keywords: Seismic hazard assessment; uniform hazard spectra; historical earthquakes; seismicity parameters; Shiraz; Iran.

1. INTRODUCTION

Iran is a country which has high risk of earthquake happening. This country is on Alpine-Caucasian-Himalayan belt and many catastrophic earthquakes have destroyed and damaged some parts of it and killed many people. Figure 1 shows recent seismicity of Iran [1].

Shiraz; center of Fars province; is the most important city in south of Iran because of its historical places and its population. This city has damaged and destroyed several times in the previous years; therefore, in the Iranian code of practice for seismic resistant design of

*E-mail address of the corresponding author: ghodrati@iust.ac.it (G. Ghodrati Amiri)

buildings [2], it has placed in high seismic risk region and the base acceleration of 0.3g is recommended for it. (Fig. 1)

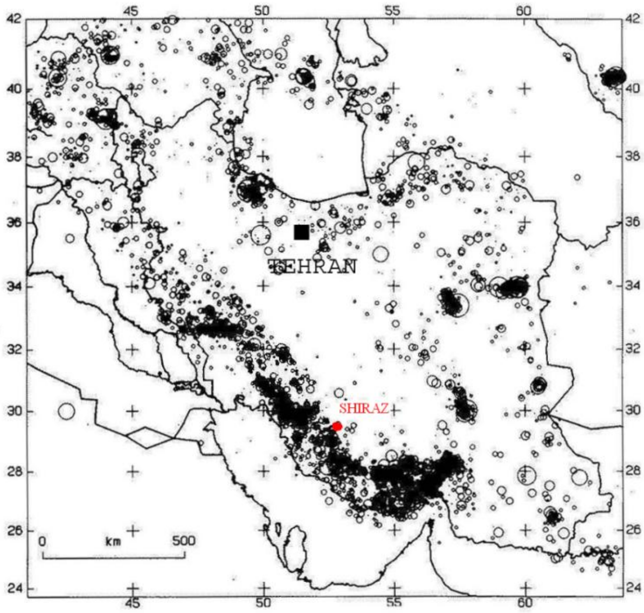

Figure 1. Recent seismicity map of Iran [1]

With regard to the historical importance of this city with more than 2500 years history and a lot of historical places and this issue that seismic hazard analysis with high accuracy has not been done for Shiraz so far; in this study it has been emphasized to achieve design spectrum over bedrock, curve of magnitude-return period and seismic graphs in two levels of hazard for Shiraz city.

2. SEISMOTECTONIC STRUCTURE OF SHIRAZ

In order to evaluate the hazard spectrum of a region or zone, all the probable seismic sources have to be detected and their potential to produce strong ground motion must be checked. The major faults in Shiraz region and its vicinity are Sabzposhan, Kohenjan, Sarvestan and Karehbas. The list of active faults in this region are given in Table 1 and shown in Fig 2.

Table 1: Main active faults of Shiraz and its vicinity [3]

NO.	Fault	Length (Km)	Observation Magnitude
1	Sabzposhan	51	M_S=6.5, 6.2, 6.2, 4.2, 4
2	Kohenjan	75	M_S=4.8, 4.5
3	Mishvan	55	M_S=4.5, 4.4
4	Karehbas	63	M_S=4.7, 4.1, 4.1
5	Sarvestan	75	M_S=7.5, 6.4, 5, 4.6, 4.3, 4.2, 4
6	Goarm	32	m_b=5, 4.9, 4.7, 4.4, 4.3

7	Bazin	23	M_S=4.3
8	Soltan	45	M_S=4.4
9	Kovar	53	m_b=5.2, 4.8, 4.6, 4.5
10	Shorab	70	m_b=4.8, 4.4
11	Rahdar	72	M_S=6.3, 5.2, 5.1, 4.9, 4.6, 4.5, 4.3, 4.2

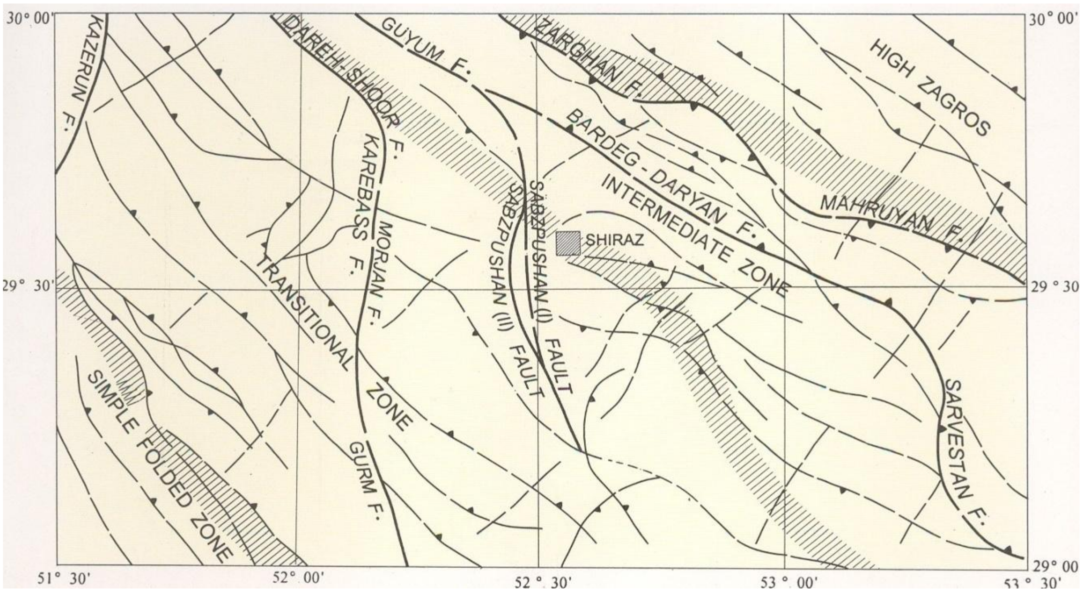

Figure 2. Active faults of Shiraz and its vicinity [3]

3. SEISMICITY OF SHIRAZ

The happened earthquakes in this area have been categorized, with respect to information accuracy, into two categories:

1) Historical earthquakes (earthquakes occurred before the year 1900).

2) Instrumentally recorded earthquakes (earthquakes occurred from the year 1900 up to now).

Our knowledge of earthquakes that occurred before the 20th century is based on data collection from historical and ancient documents; as a result, overestimation might be present in the data. The magnitude of historical earthquakes due to the destructive effects and their social outcomes have been estimated by researchers like Berberian [4] and Ambarasys and Melville [5] by consideration of many historical notes.

The investigation of the catalogue of earthquakes shows that several earthquakes have occurred with M>6. The historical studies show that Shiraz has been completely destroyed at least twice in the past.

Seismic data after 1900 are more important since instruments recorded them although they might possess different inaccuracies in the location of epicenter, and amount of focal depth and earthquake magnitude.

4. THE SEISMICITY PARAMETERS OF THIS AREA

The seismic assessment is based on data of the earthquakes occurred in the concerned region and utilization of probabilistic methods. The earthquakes catalogue in a radius of 200 km has been gathered and processed, assuming that the earthquakes follow a poisson distribution.

The seismic parameters, such as α , β and $M_{\max}$ were calculated using the Kijko [6] method.

4.1 Earthquakes catalogue

The information of the earthquakes in radius of 200 km of Shiraz has been gathered from several references like Ambraseys and Melville [5], Building and Housing Research Center (BHRC) [7], International Institute of Earthquake Engineering and Seismology (IIEES) [8] and some websites like USGS [9]. The reason for the application of probabilistic method and its advantage over the other methods is for the incompleteness of our seismic data regarding magnitude and focal depth of earthquakes.

The types of magnitude scales were not the same. To change these types to one scale, Equation 1, presented by the Iranian Committee of Large Dams IRCOLD [10] was employed to transfer mb (body wave magnitude) into M_S (surface wave magnitude):

$$M_S=1.2mb-1.29 \tag{1}$$

Since foreshocks and aftershocks are events that happen before and after earthquakes (main shock) respectively, therefore the complete list of earthquakes (without the elimination of foreshocks and aftershocks) usually do not follow Poisson distribution, as a result all foreshocks and aftershocks must be excluded. 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 [11].

4.2 Determination of seismicity parameters based on Kijko method

In order to perform seismic hazard analysis, it is necessary to evaluate the seismicity parameters such as maximum expected magnitude (Mmax), annual activity rate of earthquake λ and b value of Gutenberg-Richter [12] relation.

The seismicity parameters are calculated based on the occurrence of earthquakes and the relationship between their magnitudes and frequencies. So far, several methods have presented to evaluate these coefficients based on Gutenberg- Richter relationship [12].

With regard to the importance of these parameters to determine seismic hazard; in this paper, the result of Tavakoli [13] parameters and also Kijko [6] method are used. In order to combine these results, logic tree method has been used with equal contribution coefficients.

Kijko [6] method parameters have been obtained based on Gutenberg- Richter [12] relationship and estimation of maximum expected magnitude. In this method, both historical and instrumental earthquakes can be used with suitable classification and also in its program the uncertainty of the earthquake, data are mentioned.

There are three groups of earthquakes data in this method; as follows:

Historical earthquakes (before 1900) with magnitude uncertainty between 0.3 and 0.5

(Case 1).

Instrumentally recorded earthquakes from 1900 to 1963 with uncertainty 0.2 (Case 2)

Instrumentally recorded earthquakes from 1964 to 2013 with uncertainty 0.1 (Case 3)

The results of this method are shown in Table 2 and Fig. 3.

Table 2: Seismicity parameters in different cases for Shiraz

Catalog	Parameters	Value	Data contribution to the parameters		
			Case 1	Case 2	Case 3
Instrumental Earthquakes	Beta	1.8		37.8	62.2
	Lambda (for M_S=4)	1.16		15.2	84.8
Historical Earthquakes	Beta	1.94	100		
	Lambda (for M_S=4)	0.24	100		
Instrumental & Historical Earthquakes	Beta	1.98	38.7	22.4	38.9
	Lambda (for M_S=4)	0.9	7.4	14	78.5

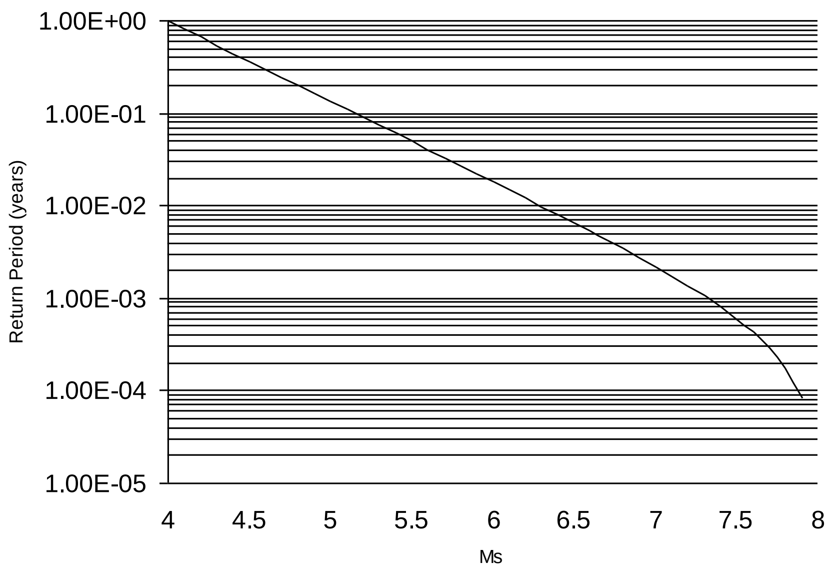

Figure 3. Annual rates estimated by Kijko[6] method for Shiraz and its vicinity

4.3 Determining seismicity parameters based on Tavakoli's results

Tavakoli [13] has divided Iran into 20 seismotectonic provinces, as shown in Fig. 4 and earthquake hazard parameters have been evaluated for each seismotectonic province. In this study, the maximum likelihood method [14] was applied. Suggested values for seismicity parameters for Shiraz (province No. 12) are shown in Table 3. In addition, these parameters were used in this paper through logic tree method. Note that to some extent, this method compensates the assumption of seismic homogeneity in the radius of 200 km around Shiraz.

Table 3: Seismicity parameters for seismotectonic province of Shiraz [13]

Province No.	Span of Time	Beta	M_{max}	Lambda (M_S = 4.5)
12	1920-1995	2.12 ± 0.05	7.2 ± 0.2	1.7

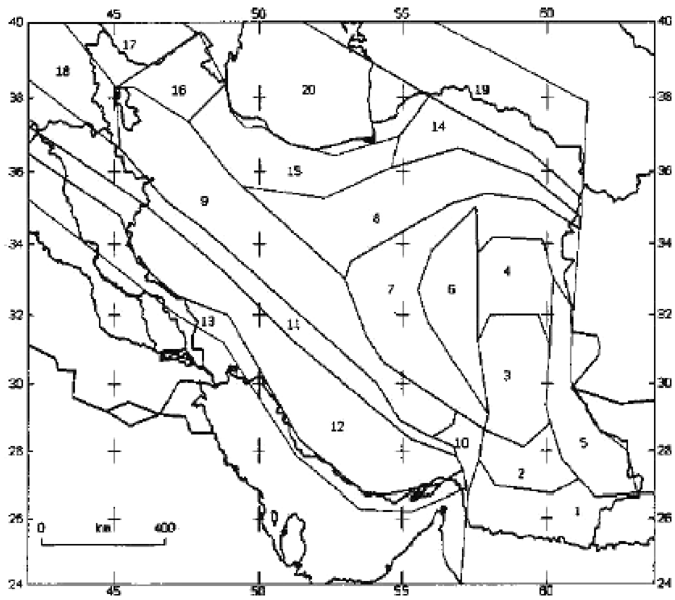

Figure 4. Seismotectonic provinces of Iran [13]

5. SEISMIC HAZARD ANALYSIS

In this part, probabilistic seismic hazard analysis is used for determining spectral ordinates for two hazard levels. This procedure is divided into five steps:

Collecting of earthquakes catalogue,

Recognition of seismic sources and modeling of them,

Calculating of seismicity parameters by Kijko [6] method and using Tavakoli's seismicity parameters,

Selection of suitable attenuation relationships,

Deriving the amount of spectrum at this area by dividing it into subzones with software SEISRISK III [15].

Around first three steps, it has been discussed enough before, but about steps 4 and 5 some information will be mentioned in the following.

5.1 Attenuation Relationships

Attenuation relationship is one of the most important parameters in seismic hazard analysis that displays the amount of Spectrum in different distance and magnitude of earthquakes.

In this study after assessment of available relationships, finally three attenuation relationships have been selected: Ambraseys et al. [16], Berge-Thierry et al. [17] and Cambpbell [18]. Their logic tree coefficients for these relations are 0.3, 0.3 and 0.4, respectively.

5.2 Relationship between maximum expected magnitude and fault rupture length

The relationship between maximum expected magnitude and fault length depends on the understanding of the seismotectonic and geotectonic behavior of the concerned area. In general, Eq. (2) for any given region can be written:

$$\text{Log } L = a + bM \tag{2}$$

where, L is rupture length, M is maximum expected magnitude, and a and b are constant coefficients. The rupture length is a percentage of fault length, which causes the earthquake and varies for different fault lengths. Nowroozi [19] has offered Eq. (3) after studying over ten severe earthquakes in Iran and observing active faults ruptures. The faults under study include Zagros fault, North Alborz fault, North Tabriz fault, Zafareh fault in north of Isfahan, Dehshir fault in southeast of Isfahan, the fault of Babak city in Kerman and the faults of Doroone and Dasht-e-Bayaz in Makran region.

$$M_S = 1.259 + 1.244 \log(L) \tag{3}$$

In Eq. (3), M_S is surface wave magnitude and L is rupture length in meters.

5.3 Uniform hazard spectra

In order to analysis, at first, based on the faults map in Fig. 2, the seismic sources are modeled into linear and area forms, and the seismicity parameters are calculated, then results are introduced by SEISRISK III [15] software.

Output of SEISRISK III [15] with utilizing logic tree is shown in sec. 5-1 contains spectral ordinates over bedrock in two return periods: 475 and 2475 years, respectively.

These return periods are according to the hazard levels in Instruction for Seismic Rehabilitation of Existing Buildings [20]. This procedure has done for many nodes at Shiraz city and isospectral graf for two hazard levels in maximum, mean and minimum amount of nodes have achieved. These grafs have presented in Figs. 5 to 12.

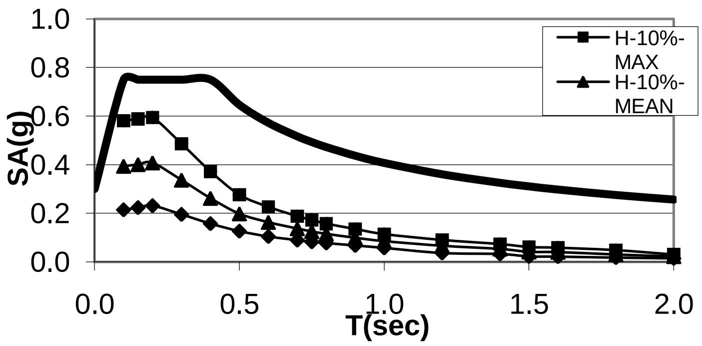

Figure 5. Final Spectral ordinates of Shiraz and its vicinity using logic tree for 475-year return period in soil type I

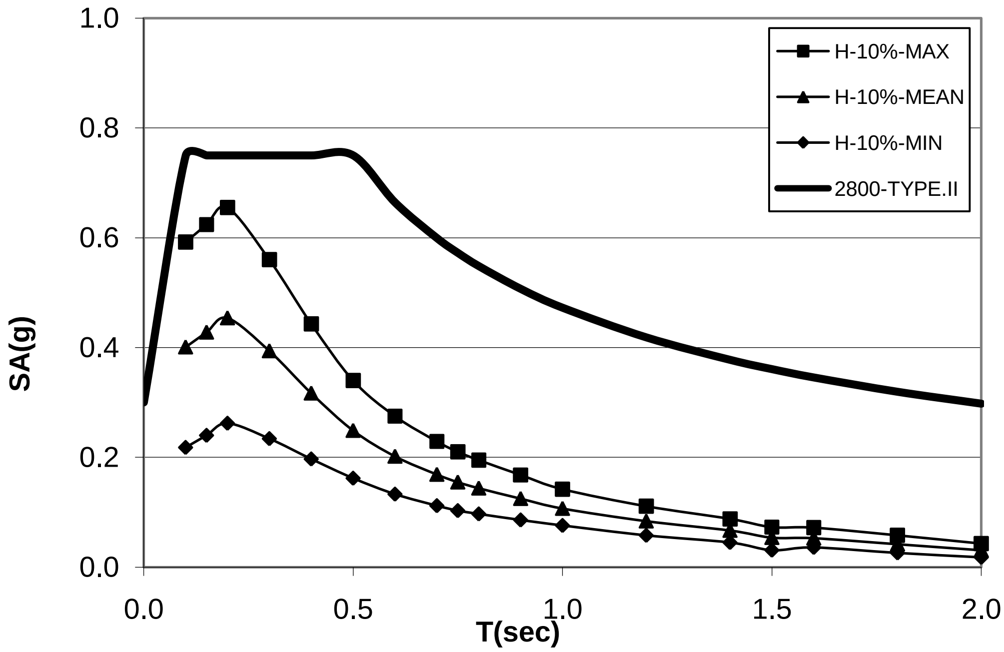

Figure 6. Final Spectral ordinates of Shiraz and its vicinity using logic tree for 475-year return period in soil type II

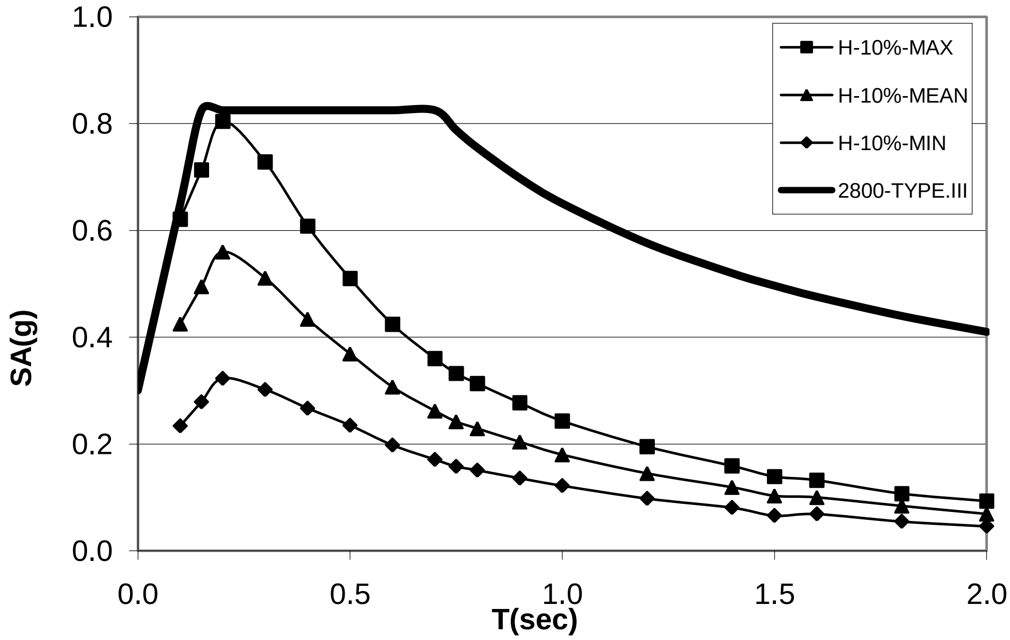

Figure 7. Final Spectral ordinates of Shiraz and its vicinity using logic tree for 475-year return period in soil type III

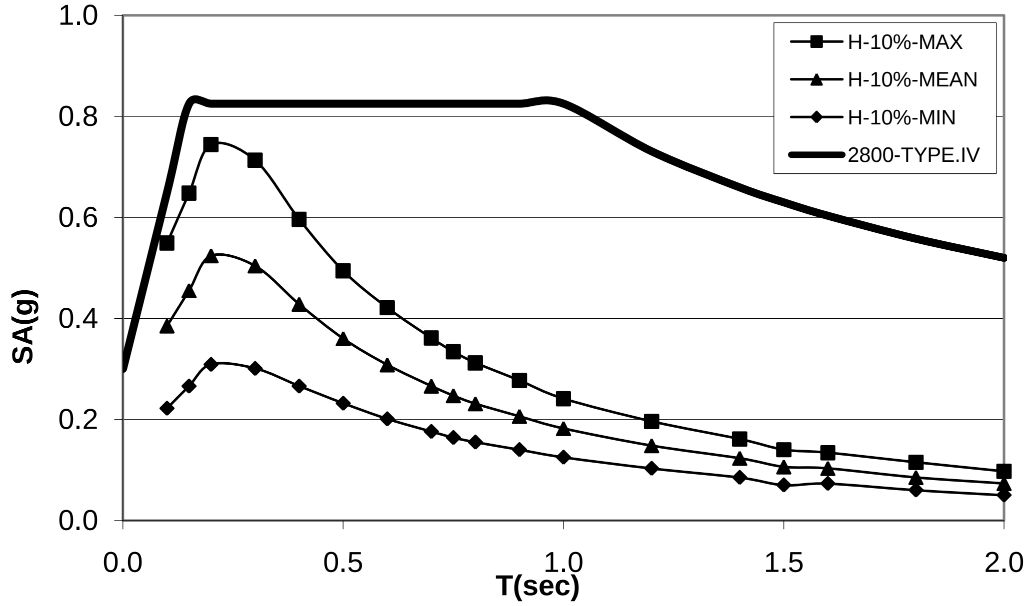

Figure 8. Final Spectral ordinates of Shiraz and its vicinity using logic tree for 475-year return period in soil type IV

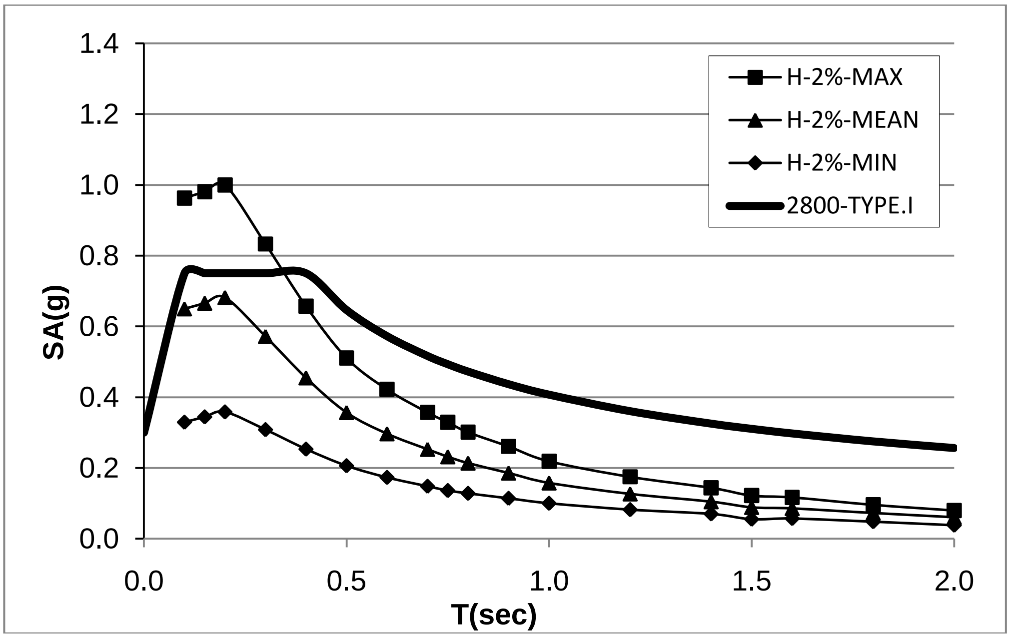

Figure 9. Final Spectral ordinates of Shiraz and its vicinity using logic tree for 2475-year return period in soil type I

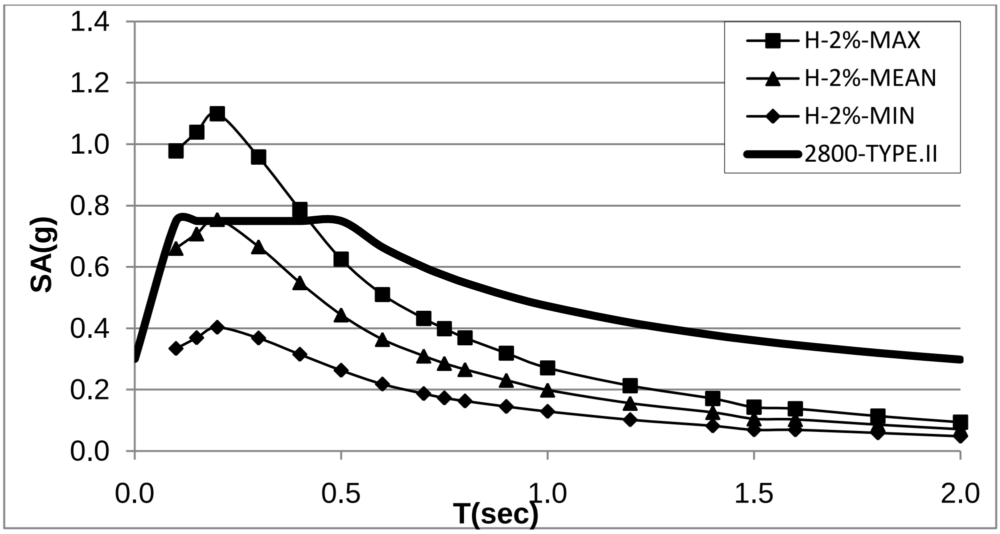

Figure 10. Final Spectral ordinates of Shiraz and its vicinity using logic tree for 2475-year return period in soil type II

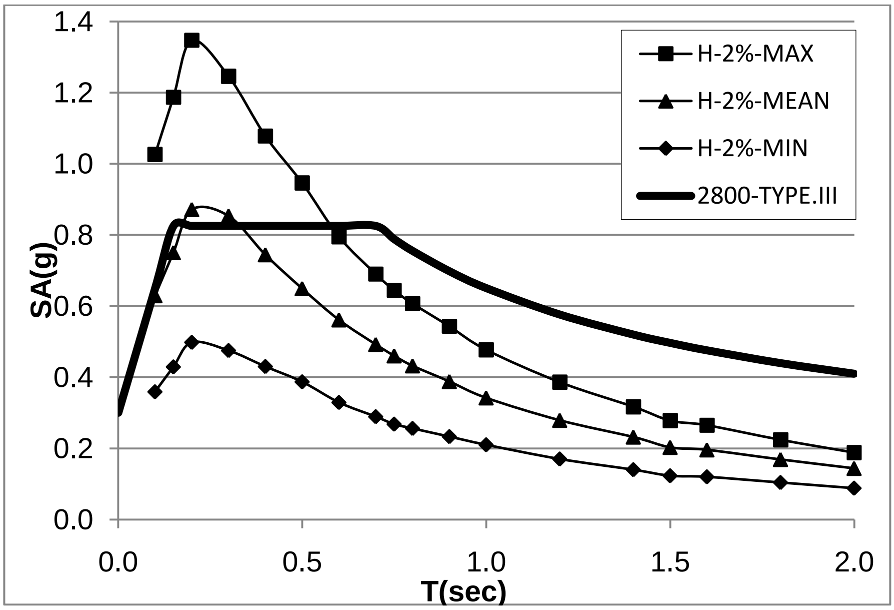

Figure 11. Final Spectral ordinates of Shiraz and its vicinity using logic tree for 2475-year return period in soil type III

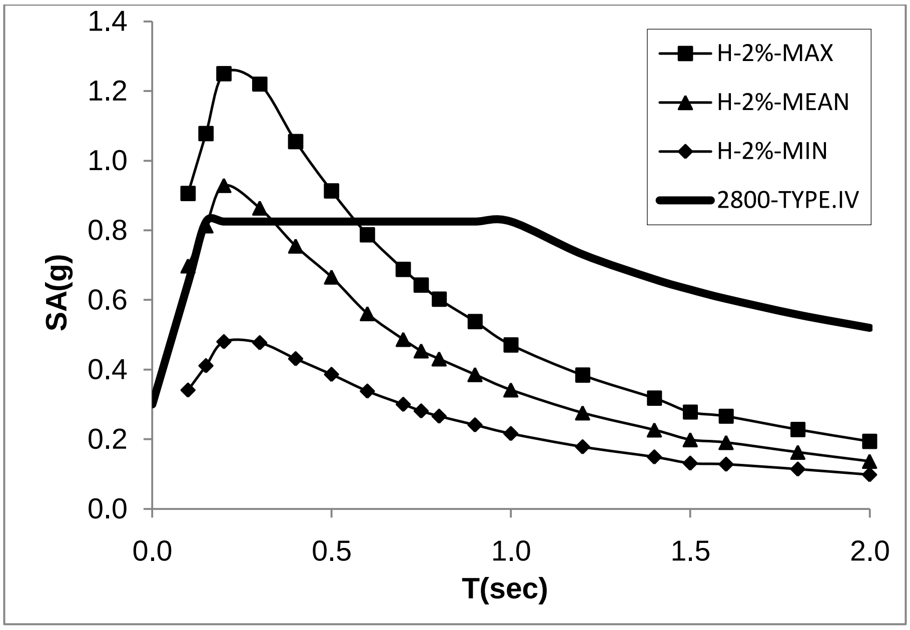

Figure 12. Final Spectral ordinates of Shiraz and its vicinity using logic tree for 2475-year return period in soil type IV

6. CONCLUSIONS

This research studied uniform hazard spectra for Shiraz and its vicinity based on probabilistic approach. The significant result of this study can be summarized as: (l) generation of a preliminary uniform hazard spectra that can be used, with caution, as a guide for determining the design earthquake and (2) utilization of different worldwide attenuation relationships using logic tree method.

This research presents the uniform hazard spectra for two levels of hazard in four soil types as what Seismic Rehabilitation Code for Existing Buildings in Iran [20] needs.

The comparison of the results with the recommended SA in Iranian Code of Practice for Seismic Resistant Design of Buildings [7] (0.75g, 0.825g) shows that:

1. The recommended SA and what has been achieved in this study in maximum amount are same together for 475-year return period.
2. The recommended SA is upper than what it has been achieved in this study in soil types I, II and the same amount in soil types III, IV for 475-year return period.
3. The recommended SA and what it has been achieved in this study in mean amount are same together for 2475-year return period.
4. The recommended SA is upper than what it has been achieved in this study in soil type I, and the same amount in soil type II and lower than what it has been achieved in soil types III, IV for 2475-year return period.
5. The Variations amount of maximum spectrum is 0.594g to 0.75g in soil type I, 0.655g to 0.75g in soil type II, 0.804g to 0.825g in soil type III and 0.744g to 0.825g in soil type IV for 475-year return period.
6. The Variations amount of maximum spectrum is 0.75g to 1.00g in soil type I, 0.75g to

1.099g in soil type II, 0.825g to 1.347g in soil type III and 0.825g to 1.25g in soil type IV for 2475-year return period.

This SA can cause major structural damage in important structures and lifeline systems.

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