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Seismic Hazard Assessment of Shiraz, Iran

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Abstract: Seismic Hazard Assessment has been done for Shiraz city in this study and four maps have been prepared to indicate the probabilistic estimate of Peak Ground Acceleration (PGA) over bedrock in this area. For this assessment first, earthquake catalogue and main active fault in a radius of 200 km have been gathered and processed and then seismicity parameters by Kijko's method and Tavakoli's method have been obtained, after that the results with four attenuation relationships have introduced to the computer program of seismic hazard analysis "SEISRISKIII" and eventually with combination of the outputs by logic tree technique, the isoacceleration maps in four levels of hazard; which are needed for retrofit of building in Seismic Rehabilitation Code for Existing Buildings in Iran; have been calculated. The results show that the ranges of PGA for 75, 225, 475 and 2475 year return periods are 0.10 to 0.17 g, 0.15 to 0.29 g, 0.18 to 0.39 g and 0.26 to 0.66 g, respectively.

Key words: Seismic hazard assessment, historical earthquakes, seismicity parameters, Shiraz, Iran

INTRODUCTION

Iran is a country which has high risk of earthquake happening. This country is located 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 (Tavakoli and Ghafory-Ashtiany, 1999).

Shiraz; center of Fars province; is the most important city in south of Iran because of its historical places and population. Cultural, economical, social and political importance of Shiraz in addition with the high risk of earthquake happening of this city and its province indicate the necessity of seismic investigation with high accuracy.

This city has been damaged and destroyed several times in previous years (Andalibi and Oveisi, 1999); therefore, in the Iranian Code of Practice for Seismic Resistant Design of Buildings (2005), it has been placed in high seismic risk region and the base acceleration of 0.3 g is recommended for it.

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

SEISMOTECTONIC STRUCTURE OF SHIRAZ

In order to evaluate the seismic hazard 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 and their specifications in this region are given in Table 1 and shown in Fig. 2.

SEISMICITY OF SHIRAZ

The happened earthquakes in this area have categorized with respect to information accuracy, into two categories (Kijko, 2000):

- Historical earthquakes (earthquakes occurred before the year 1900)
- Instrumentally recorded earthquakes (earthquakes occurred from the year 1900 up to now).

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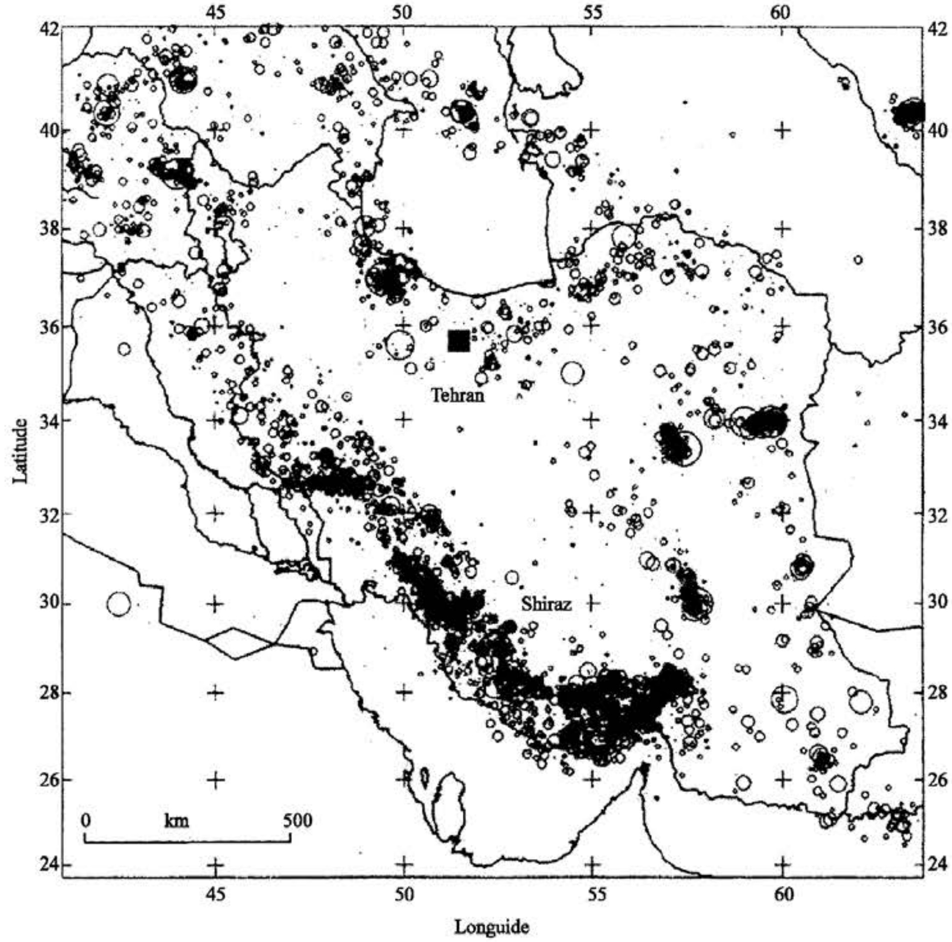

Fig. 1: Recent seismicity map of Iran. Earthquake magnitude (Richter scale): ● for M<5; ○ for M= 5-7; ◯ for M>7 (Tavakoli and Ghafory-Ashtiany, 1999)

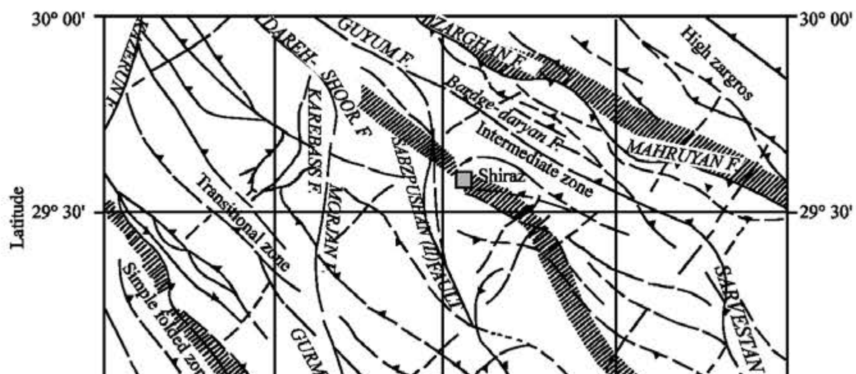

Fig. 2: Active faults of Shiraz and its vicinity (Andalibi and Oveisi, 1999)

Table 1: The list of main active faults of Shiraz and its vicinity (Andalibi and Oveisi, 1999)

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

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 (1976) and Ambraseys and Melville (1982) by consideration of many historical notes.

The investigation of the catalog 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 (Andalibi and Oveisi, 1999).

Seismic data after the year 1900 are important since instruments record them, although they might possess different inaccuracies in the location of epicenter, amount of focal depth and earthquake magnitude. The list of earthquakes occurred in the radius of 200 km from Shiraz is shown in Appendix A.

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 catalog 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 and β and M_{max} were calculated using the Kijko (2000) method.

Earthquakes catalogue: The information of the earthquakes in radius of 200 km of Shiraz, has been gathered from several references like Ambraseys and Melville (1982), Building and Housing Research Center (BHRC) (http.//www.bhrc.ir), International Institute of Earthquake Engineering and Seismology (IIEES) (http://www.iiees.ac.ir.) and some websites like USGS (http://www.usgs.gov.). The reason for the application of probabilistic method and its advantage over other methods are 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 (1994) was employed to transfer m_b (body wave magnitude) into M_S (surface wave magnitude):

$$M_S = 1.2m_b - 1.29 \quad (1)$$

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 (1974).

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 (M_{max}), annual activity rate of earthquake λ and b value of Gutenberg and Richter (1954) 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 and Richter (1954) relationship.

With regard to the importance of these parameters to determine seismic hazard; in this paper, the result of Tavakoli (1996) parameters and also Kijko (2000) method are used. In order to combine these results, logic tree method has been used with equal contribution coefficients.

Kijko (2000) method parameters have obtained based on Gutenberg and Richter (1954) 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 2005 with uncertainty 0.1 (Case 3).

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

Determining seismicity parameters based on tavakoli's results: Tavakoli (1996) 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 (Kijko and Sellevoll, 1992) has been applied. Suggested values for seismicity parameters for Shiraz (province No. 12) are shown in Table 3. In addition, these parameters were used in this study 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.

SEISMIC HAZARD ANALYSIS

There are several models for forecasting the occurrence of earthquakes (Kiremidjian and Anagnos, 1983). The most commonly used models are Poisson model (Cornell, 1968; Cornell and Merz, 1975), a time-independent model and Markov model (Chiang *et al.*, 1984), which is a time-dependent model. Poisson distribution assumes that earthquakes are independent events that occur randomly in time. In this study, Poisson model was adopted for its popularity, ease of use and lack of sufficient data for other models.

The Poisson model is given by:

$$p_n(t) = \frac{e^{-\nu t}(\nu t)^n}{n!} \qquad n = 0,1,2,... \tag{2}$$

Where:
$p_n(t)$ = Probability of having n events in time period t
n = No. of events
ν = The mean rate of occurrence per unit time

The magnitude probability density function, f_M (M), can be evaluated from Gutenberg-Richter recurrence relationship proposed:

$$\text{Log } N = a - b \times M \tag{3}$$

or:

$$\lambda = e^{(\alpha - \beta \times M)} \tag{4}$$

Where:
α = a×Ln 10
β = b×Ln 10
λ = Activity rate

Considering the magnitude uncertainty proposed by Kijko and Sellevoll (1992), the modified probability density function of magnitude, f (x|m, σ) and probability cumulative function of magnitude, F (x|m, σ), can be written as:

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	1.80		37.8	62.2
	Lambda (for M_S = 4)	1.16		15.2	84.8
Historical earthquakes	Beta	1.94	100.0		
	Lambda (for M_S = 4)	0.24	100.0		
Instrumental and historical earthquake	Beta	1.98	38.7	22.4	38.9
	Lambda (for M_S = 4)	0.90	7.4	14.0	78.5

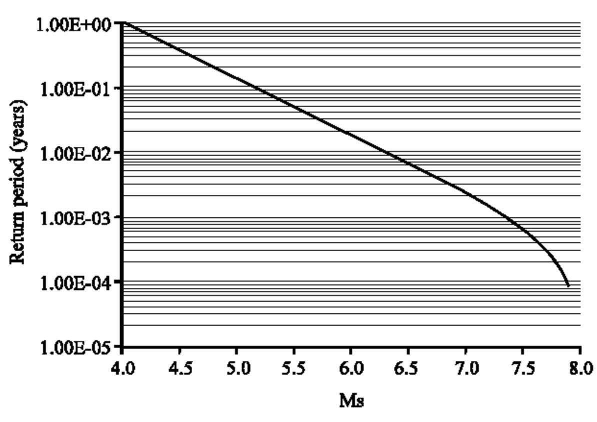

Fig. 3: Annual rates estimated by Kijko (2000) method for Shiraz and its vicinity

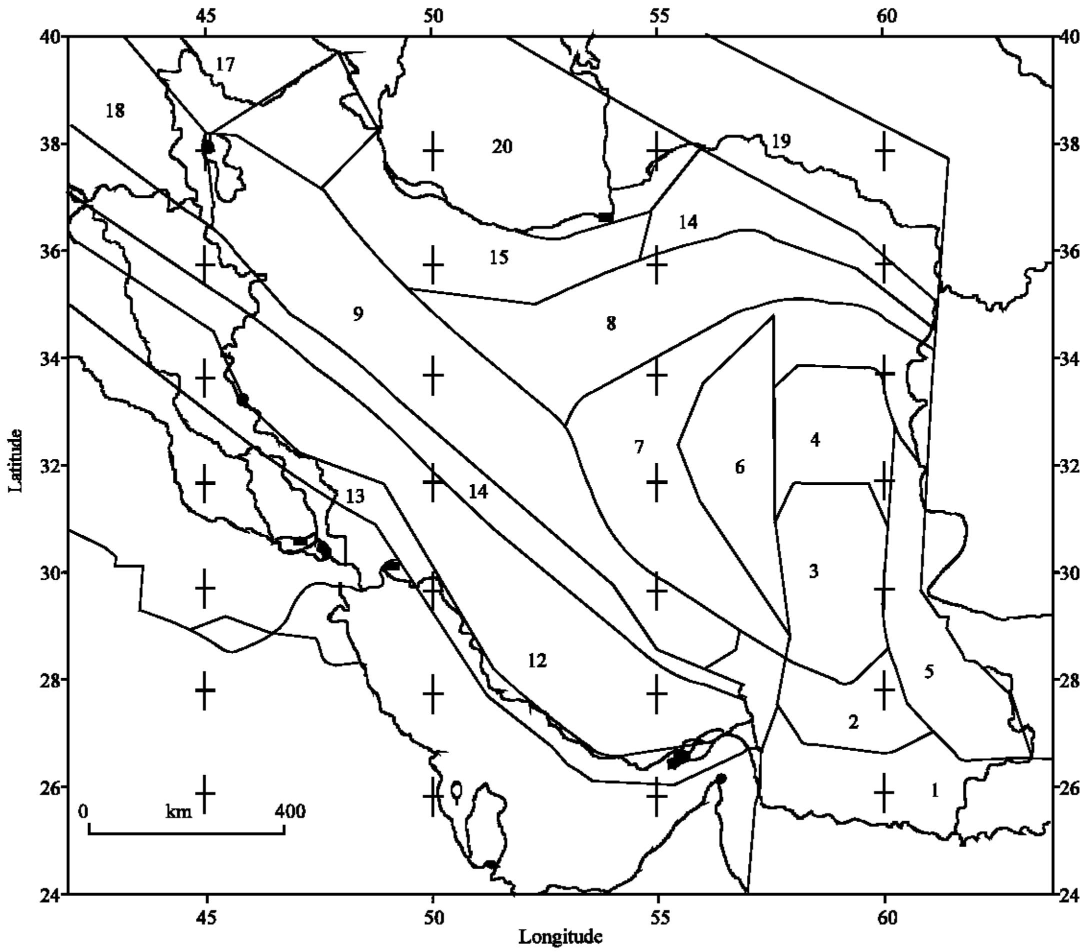

Fig. 4: Seismotectonic provinces of Iran (Tavakoli, 1996)

Table 3: Seismicity parameters for seismotectonic province of Shiraz (Tavakoli, 1996)

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

$$f(x|m,\sigma) = \beta A(x)/(A_1 - A_2)C_\sigma(x|m,\sigma)$$
$$F(x|m,\sigma) = [A_1 - A(x)]/(A_1 - A_2)D_\sigma(x|m,\sigma) \quad (5)$$

Where:

C_σ (x|m, σ) and D_σ (x|m, σ) = Correction functions
A_1 = Exp (-βm)
A_2 = Exp (-βm_{max})
σ = The error of reported magnitude and magnitude x belongs to the domain ⟨m, m_{max}⟩
m = The threshold magnitude
m_{max} = The maximum expected magnitude

In this part, probabilistic seismic hazard analysis is used for determining peak ground acceleration for four 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 (2000) method and using Tavakoli's seismicity parameters.
- Selection of suitable attenuation relationships.
- Deriving the amount of PGA at this area by dividing it into subzones with software SEISRISK III (Bender and Perkins, 1987).

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

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

In this study after assessment of available relationships, finally four relations have been selected by Ambraseys and Bommer (1991), Sarma and Srbulov (1996), Ramazi (1999) and Ghodrati Amiri *et al*. (2007). Their logic tree coefficients for these relations are 0.1, 0.1, 0.3 and 0.5, respectively.

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. 6 for any given region can be written:

$$\log L = a + bM \quad (6)$$

Where:

L = Rupture length
M = Maximum expected magnitude
a and b = Constant coefficients.

The rupture length is a percentage of fault length, which causes the earthquake and varies for different fault lengths. Nowroozi (1985) has offered Eq. 7 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.

$$M_S = 1.259 + 1.244 \log (L) \quad (7)$$

In Eq. 7, M_S is surface wave magnitude and L is rupture length in meters.

Probabilistic seismic hazard analysis: 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 calculated, then results are introduced by SEISRISK III (Bender and Perkins, 1987) software. Then the whole area of interest was subdivided into a grid of 8*7, total of 56 sites and probabilistic seismic hazard analysis was carried out for each site. The output of program was the anticipated Peak Ground Acceleration in g with 2, 10, 20 and 50% probabilities of being exceeded during life cycles of 50 years or for the ground motion return periods of 75, 225, 475 and 2475 years. As shown in Fig. 5, logic tree analysis has been utilized for the output of SEISRISK III.

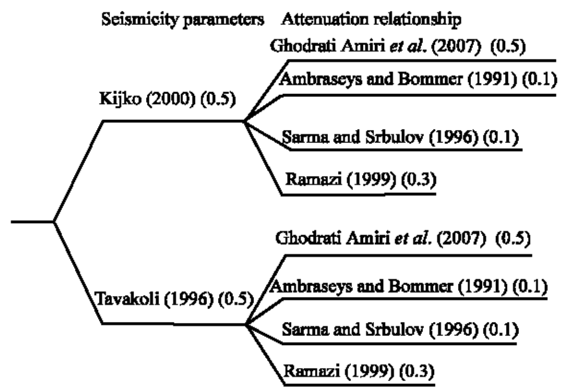

Fig. 5: Applied logic tree for seismic hazard analysis

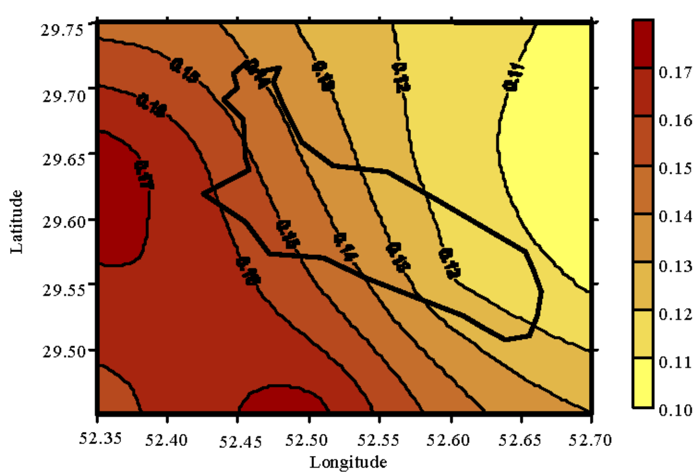

Fig. 6: Final zoning map (PGA over bedrock) of Shiraz and its vicinity using logic tree for 75-year return period map and the border of Shiraz (thick line)

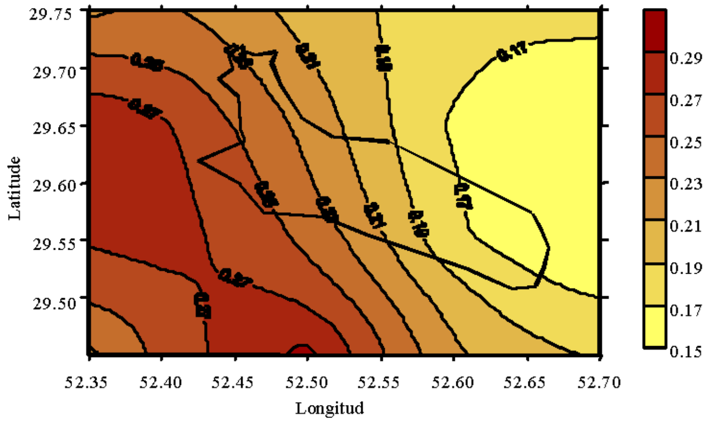

Fig. 7: Final zoning map (PGA over bedrock) of Shiraz and its vicinity using logic tree for 225-year return period and the border of Shiraz (thick line)

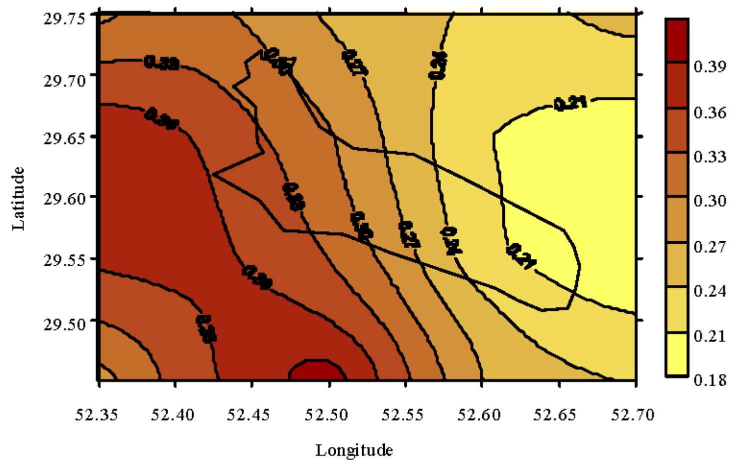

Fig. 8: Final zoning map (PGA over bedrock) of Shiraz and its vicinity using logic tree for 475-year return period and the border of Shiraz (thick line)

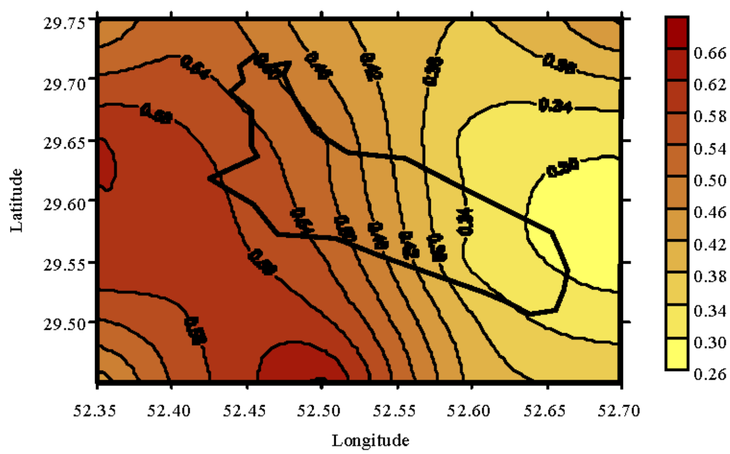

Fig. 9: Final zoning map (PGA over bedrock) of Shiraz and its vicinity using logic tree for 2475-year return period and the border of Shiraz (thick line)

These return periods used in this study are according to the hazard levels in Seismic Rehabilitation Code for Existing Buildings in Iran (IIEES, 2002). Isoacceleration maps for four hazard levels have been shown in Fig. 6-9. With regard to these maps, it is obvious that south-west of Shiraz has the most probable seismic acceleration.

CONCLUSIONS

This research studied seismic hazard and seismic zoning of Shiraz and its vicinity based on probabilistic approach. The significant results of this study can be summarized as: (1) generation of a preliminary seismic zoning map (PGA over bedrock) that can be used, with caution, as a guide for determining the design earthquake, (2) production of an updated and complete earthquake catalogue considering both historical and instrumental events (Appendix A) and (3) utilization of different worldwide attenuation relationships using logic tree method. The seismic hazard analysis carried out in this study was based on the assumption of an ideal bedrock case and therefore no influence of local soil condition is taken into consideration.

This research presents the maps of maximum probable acceleration over bedrock for four levels of hazard as what Seismic Rehabilitation Code for Existing Buildings in Iran (IIEES, 2002) needs. The PGA in the interested area, ranges from 0.1 to 0.17 g for a return period of 75 years, 0.15 to 0.29 g for a return period of 225 years, 0.18 to 0.39 g for a return period of 475 years and from 0.26 to 0.66 g for a return period of 2475 years.

The comparison of the results with the recommended PGA in Iranian Code of Practice for Seismic Resistant Design of Buildings (http:www.bhrc.ir) (0.3 g) shows that the recommended PGA is lower than what it has been achieved in this study in some parts of the region. The south-west of Shiraz has the most probable seismic acceleration. This PGA can cause major structural damage in important structures and lifeline systems.

APPENDIX A

Earthquake catalogue in the radius of 200 km for Shiraz

Date			GMT			Epicenter		F.D.	Magnitude	
Year	Month	Day	h	m	s	LAT-N	LONG-E	(km)	mb	Ms
1440						28.40	53.10			7.1
1506						29.60	52.50			5.5
1589	11	9				29.80	52.40			5.9
1591						29.80	52.40			5.9
1623						29.90	52.90			5.5
1824	6	25				29.80	52.40			6.4
1853	5	5				29.60	52.50			6.2
1862	12	21				29.50	52.50			6.2
1865	6					29.60	53.10			6.0
1890	3	25				28.80	53.50			6.4
1892	8	15				29.10	52.70			5.3
1894	2	26				29.50	53.30			5.9
1925	7	30	18	43	10	30.00	51.00		5.2	5.0
1927	7	30	4	4	40	28.70	51.90		4.5	4.2
1928	4	15	10	9	28	28.70	51.90		4.7	4.4
1928	8	26	23	16	21	28.70	51.90		4.5	4.2
1929	7	16	19	43	15	28.70	51.90		4.7	4.4
1930	2	15	19	7	6	28.70	51.90		5.0	4.8
1930	9	2	18	58	52	29.40	51.40		5.5	5.4
1931	7	28	17	36	32	29.40	51.40		5.0	4.8
1934	2	4	13	27	20	30.50	51.70		6.0	6.0
1935	10	15	17	2	42	28.70	51.90		4.5	4.2
1936	8	20	2	8	49	30.50	51.70		5.0	4.8
1937	5	21	0	56	24	29.00	54.00		4.5	4.2
1939	1	25	11	2	19	30.30	50.80		5.2	5.0
1946	3	12	2	21	54	29.80	51.80		5.7	5.6
1947	1	2	14	11	3	28.50	51.50		4.5	4.2
1949	3	6	16	36	40	29.80	51.80		5.2	5.0
1952	8	1	10	30	35	29.80	51.80		4.7	4.4
1957	9	5	11	36	5	28.51	53.61		5.5	5.4
1958	4	9	4	36	30	29.05	52.01		5.5	5.4
1958	6	10	7	4	2	30.27	51.11		5.5	5.4
1960	7	4	3	43	35.0	30.00	52.00		4.5	4.2
1960	9	25	8	36	27.6	28.40	53.20	53	4.5	4.2
1962	2	3	3	0	0.0	30.20	52.00		4.5	4.2

Continued

Date			GMT			Epicenter		F.D.	Magnitude	
Year	Month	Day	h	m	s	LAT-N	LONG-E	(km)	mb	Ms
1963	5	3	10	44	29.6	30.70	51.80	35	5.3	5.1
1963	5	29	0	47	49.0	28.16	52.50	44	4.5	4.2
1963	7	13	8	24	25.0	29.63	50.88	43	5	4.8
1964	2	16	0	17	15.5	30.03	51.17	33	5.3	5.1
1964	6	9	3	38	8.5	28.86	52.76	59	4.9	4.6
1964	8	20	5	39	45.6	28.18	52.62	33	5.6	5.5
1964	11	8	10	33	27.0	29.63	50.95	36	5.2	5.0
1965	6	18	13	49	37.0	29.72	51.37	65	5	4.8
1966	7	29	8	20	46.8	28.34	51.62	38	4.7	4.4
1967	4	6	12	57	15.0	29.91	51.02	20	5.2	5.0
1967	5	20	21	48	54.0	29.63	52.18	32	4.5	4.2
1967	8	2	13	55	14.0	30.90	53.50	33	4.5	4.2
1967	11	15	19	35	46.3	30.70	51.40	10	4.6	4.3
1968	1	2	11	59	33.0	29.53	52.56	34	4.8	4.5
1968	3	26	4	42	24.8	29.91	51.84	62	4.9	4.6
1968	5	30	19	53	5.0	29.70	51.24	22	5.2	5.0
1968	6	15	0	8	29.7	29.80	51.93	88	4.5	4.2
1968	6	23	9	16	18.0	29.76	51.24	32	5.3	5.1
1968	7	12	10	34	3.1	29.80	50.60	24	4.8	4.5
1968	9	14	13	48	26.0	28.30	53.17	3	5.8	5.7
1969	4	29	4	37	40.7	29.60	51.50	36	5.6	5.5
1970	1	20	11	0	13.1	30.70	51.40	25	4.9	4.6
1970	5	11	3	12	19.7	28.50	52.30	22	5.1	4.9
1970	7	21	0	39	14.2	29.30	52.20	20	4.5	4.2
1970	8	20	15	29	52.2	29.30	51.60	33	4.4	4.0
1971	4	6	6	49	52.9	29.80	51.90	10	5.2	5.0
1971	6	2	10	5	9.3	29.40	51.60	35	4.8	4.5
1971	8	22	17	54	14.6	30.10	50.70		5.1	4.9
1971	11	29	21	12	37.3	29.50	52.80	18	4.9	4.6
1972	2	28	18	44	54.2	29.50	50.70	25	4.7	4.4
1972	4	10	2	6	53.2	28.40	52.80		6.1	6.1
1972	7	3	21	38	22.2	30.00	51.00	43	5.1	4.9
1973	3	3	2	46	29.1	29.79	51.19	57	5	4.8
1973	5	3	7	44	24.3	28.14	52.00	43	4.7	4.4
1973	11	11	7	14	52.4	30.53	53.00	19	5.4	5.2
1973	12	16	8	25	1.6	28.43	52.75	46	4.8	4.5
1974	12	26	18	36	21.9	29.50	52.70	33	4.8	4.5
1975	1	11	12	8	6.4	29.00	51.80	27	5	4.8
1975	5	9	18	1	45.6	30.20	51.99	57	4.9	4.6
1976	1	16	5	36	16.0	30.22	50.84	32	4.9	4.6
1976	4	22	17	3	7.9	28.71	52.13	24	6	6.0
1976	6	27	9	26	31.9	29.48	52.10	8	4.7	4.4
1976	7	17	8	36	58.5	29.67	51.47	29	4.7	4.4
1976	10	15	23	3	26.1	30.04	51.97	8	5.1	4.9
1977	5	19	0	8	15.5	29.788	51.195	40	4.9	4.6
1977	5	25	21	6	38.3	29.336	53.390	22	4.8	4.5
1977	10	27	0	22	22.3	29.737	50.685	34	4.8	4.5
1978	1	8	2	55	48.0	30.161	50.856	33	4.8	4.5
1978	8	29	14	11	4.3	29.564	51.568	34	4.9	4.6
1979	5	15	0	29	5.8	28.378	51.417	33	4.5	4.2
1979	12	24	19	54	46.6	29.101	52.064	10	4.7	4.4
1980	7	16	8	53	48.4	29.493	51.903	33	4.8	4.5
1980	11	21	12	43	25.1	28.211	52.164	33	4.6	4.3
1981	4	1	10	16	59.2	29.849	51.500	33	5.4	5.2
1981	5	20	23	38	22.5	28.237	51.775	33	4.6	4.3
1982	4	17	2	42	3.9	28.637	51.720	33	4.4	4.0
1983	7	11	20	34	10.8	29.150	51.878	40	4.6	4.3
1984	7	23	7	13	50.8	29.508	53.452	34	4.9	4.6
1985	2	2	22	40	9.0	28.396	52.866	33	4.6	4.3
1985	4	25	4	58	41.8	29.297	52.669	10	4.8	4.5
1985	5	19	0	55	11.0	29.738	51.127	33	4.7	4.4
1985	7	31	18	9	41.8	28.929	52.339	33	5.0	4.8
1985	8	19	15	23	31.7	29.715	52.344	33	4.4	4.0
1985	12	5	23	30	14.0	29.449	51.424	33	4.7	4.4
1986	1	27	3	2	4.5	28.504	51.490	33	4.6	4.3

Continued

Date			GMT			Epicenter		F.D.	Magnitude	
Year	Month	Day	h	m	s	LAT-N	LONG-E	(km)	mb	Ms
1986	5	26	21	7	1.7	29.009	51.805	33	4.6	4.3
1986	10	1	3	57	52.9	28.815	51.311	10	4.5	4.2
1986	10	16	19	1	47.9	28.978	52.731	33	4.6	4.3
1986	11	20	10	9	7.8	29.869	51.585	16	4.9	4.6
1987	1	22	17	5	32.4	29.404	51.657	25	4.4	4.0
1987	9	29	18	36	13.7	28.554	52.806	35	5.0	4.8
1988	7	6	0	10	57.9	29.370	52.490	20	4.6	4.3
1988	8	11	16	39	58.8	29.935	51.518	33	4.7	4.4
1989	5	3	9	13	24.2	29.964	51.655	33	5.1	4.9
1990	3	23	0	37	37.8	29.640	51.31	33	4.6	4.3
1990	10	26	22	18	8.0	28.40	52.46	15	4.4	4.0
1991	2	21	21	56	2.0	29.80	51.89	27	4.6	4.3
1991	4	5	0	38	18.5	29.11	51.36	35	4.9	4.6
1991	5	19	23	24	21.0	28.88	52.19	53	4.4	4.0
1991	11	29	0	24	58.7	30.14	50.86	41	4.8	4.5
1992	5	5	0	54	16.6	29.46	51.12	67	4.5	4.2
1992	8	15	0	15	17.8	28.53	51.20	43	4.8	4.5
1992	9	9	0	44	49.7	30.19	50.88	33	4.8	4.5
1992	12	11	0	44	20.7	29.03	53.09	33	4.5	4.2
1992	12	11	0	33	56.6	29.59	53.47	33	4.4	4.0
1993	2	21	0	56	44.4	29.02	52.09	33	4.5	4.2
1993	6	15	21	25	32.0	28.80	51.45	36	4.4	4.0
1993	7	17	18	48	21.0	29.80	51.44	39	4.4	4.0
1994	1	4	0	29	40.0	29.19	51.43	39	4.8	4.5
1994	6	5	0	54	8.1	29.60	52.31	33	4.5	4.2
1994	6	18	0	42	0.3	28.97	52.67	11	5.1	4.9
1995	1	21	0	2	32.1	29.02	52.05	33	4.7	4.4
1995	2	15	0	5	20.2	29.04	51.25	31	4.7	4.4
1995	2	19	0	34	46.0	28.89	53.22	33	4.4	4.0
1995	3	22	0	28	36.8	30.21	51.04	33	4.8	4.5
1995	5	3	0	49	52.6	28.40	52.76	33	4.7	4.4
1995	11	1	0	49	16.4	29.34	51.55	33	4.5	4.2
1995	12	20	0	9	21.4	28.61	51.76	33	4.5	4.2
1995	12	31	0	56	39.5	29.39	52.44	33	4.7	4.4
1996	1	24	0	7	4.7	29.41	51.03	57	4.7	4.4
1996	1	26	0	1	28.7	28.75	52.38	33	4.4	4.0
1996	7	21	0	18	42.4	28.30	52.35	33	4.6	4.3
1996	12	20	0	18	12.8	29.36	51.39	33	4.6	4.3
1997	2	15	0	47	25.9	28.95	52.64	33	4.8	4.5
1997	4	2	0	42	27.6	30.04	51.59	33	4.4	4.0
1997	4	22	17	39	38.0	28.38	52.90	33	4.8	4.5
1997	7	27	0	59	30.8	29.14	52.30	33	4.6	4.3
1997	7	28	0	18	27.3	29.90	51.06	33	4.4	4.0
1997	12	15	0	7	34.2	29.17	51.17	33	4.5	4.2
1998	1	1	0	53	43.1	29.85	51.42	33	4.6	4.3
1998	9	4	0	51	18.9	28.75	52.39	33	4.5	4.2
1998	9	29	0	9	43.8	29.36	51.33	10	4.4	4.0
1999	5	6	0	0	53.1	29.50	51.88	33	6.3	6.3
1999	6	18	0	22	51.8	28.59	52.08	33	4.4	4.0
1999	9	17	0	14	47.1	29.04	52.62	33	4.5	4.2
1999	9	24	0	17	14.8	28.67	51.32	33	5.2	5.0
1999	10	26	0	57	10.1	30.18	51.82	33	4.5	4.2
1999	10	31	0	9	39.8	29.41	51.81	33	5.0	4.8
1999	11	18	0	54	52.4	28.90	52.17	33	4.7	4.4
2000	3	11	0	8	33.1	28.70	51.34	33	4.8	4.5
2000	3	13	0	16	19.3	29.23	51.37	33	4.6	4.3
2000	5	3	0	1	16.7	29.74	50.88	33	5.1	4.9
2000	6	23	0	15	11.0	30.10	51.68	33	5.1	4.9
2001	3	28	16	34	19.3	29.88	51.05	33		4.1
2002	2	17	0	3	28.2	28.47	51.86	33		4.3
2002	5	17	0	52	18.9	29.54	51.88	6	4.6	4.3
2002	6	1	0	12	38.5	30.01	51.35	16	4.5	4.2
2003	1	11	0	45	33.0	29.68	51.21	32		4.1
2003	2	14	9	50	49.3	29.77	53.13	15		4.0
2003	3	16	5	42	4.9	28.48	53.03	33	4.6	4.3

Continued

Date			GMT			Epicenter		F.D.	Magnitude	
Year	Month	Day	h	m	s	LAT-N	LONG-E	(km)	mb	Ms
2003	5	27	10	30	50.5	29.23	51.13	33	5.0	4.8
2003	8	29	6	55	51.6	28.38	51.52	33	4.9	4.6
2003	10	4	0	44	34.4	29.76	51.67	15	4.9	4.6
2004	1	22	21	19	32.5	29.59	51.23	15		4.4
2004	3	2	7	51	53.4	29.08	51.10	33	4.5	4.2
2004	5	8	4	39	19.0	29.64	51.25	20		4.6
2004	8	16	1	23	31.7	30.26	51.73	2		4.0
2004	8	31	22	26	41.7	28.72	53.55	14		4.0
2004	12	31	18	7	38.7	28.35	53.23	16		4.4
2005	2	14	2	5	11.8	30.24	51.96	30		4.2
2005	6	22	13	37	9.8	28.24	52.90	15		4.3
2005	8	9	5	9	19.2	28.86	52.66	15		5.0
2005	8	21	12	21	33.8	30.85	51.47	14		4.0
2005	10	20	15	51	14.8	29.32	52.01	18		4.1

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