STATISTICAL PREDICTION OF THE SEQUENCE OF LARGE EARTHQUAKES IN IRAN

A.Yazdani* and M. Kowsari

Department of Civil Engineering, University of Kurdistan, Sanandaj, Iran
a.yazdani@uok.ac.ir, Milad.Kowsari@uok.ac.ir

*****Corresponding Author

(Received: February 26, 2011 – Accepted in Revised Form: October 20, 2011)

doi: *10.5829/idosi.ije.2011.24.04b.03*

Abstract The use of different probability distributions as described by the Exponential, Pareto, Lognormal, Rayleigh, and Gama probability functions applied to estimation the time of the next large earthquake ($Ms \geq 6.0$) in different seismotectonic provinces of Iran. This prediction is based on the information about past earthquake occurrences in the given region and the basic assumption that future seismic activity will follow the pattern of past activity by maximizing the conditional probability of earthquake occurrence. The estimated recurrence times and the error of estimation for different distributions have been computed for different provinces. Results indicated Exponential model seem to be better than other models in prediction of occurrence time of the next earthquake in different seismotectonic provinces.

Keywords Distribution, Earthquake occurrence, Error, Seismotectonic provinces

چکیده زمان رویداد زمین لرزه شدید ($Ms \geq 6.0$) درایالات لرزه زمین ساخت مختلف ایران به کمک توابع چگالی احتمالاتی متفاوتی نظیر نمایی، پارتو، لوگ نرمال، ریلی و گاما پیش بینی می گردد. این پیش بینی بر مبنای داده های مربوط به وقوع زمین لرزهَ های های گذشته در ایالات مختلف و این فرض اساسی است که رویداد زمین لرزه در آینده منطبق بر الگوی رویداد زلزله های گذشته است. زمان رویداد زمین لرزه به کمک بیشینه احتمال شرطی وقوع زمین لرزه محاسبه می گردد. مقادیر خطای تخمین زمان رویداد زمین لرزه در ایالات مختلف به ازای توزیع های مختلف محاسبه شده است. زمان رویداد زمین لرزه های قبلی به کمک توزیع پواسون درایالات لرزه زمین ساخت مختلف به خوبی پیش بینی می گردد

1. INTRODUCTION

The Iranian Plateau is one of the most seismically active areas of the world and frequently suffers destructive and catastrophic earthquakes that cause high losses of human life and widespread damages. The spatial distribution and magnitude of earthquake events in different regions of the Iranian Plateau are not similar. This is primarily a result of Iran's position in a 1000-km wide zone of compression between the colliding Eurasian and Arabian continents [1] and its location between the Arabian Plate in the south and southwest and the Indian Plate in the east. Iran does not appear to be a single crustal block, and the distribution of active deformation is not uniform. The shortening is thought to be concentrated in the three main active belts of Zagros, Kopeh-Dagh-Alborz-Talesh, and Central Iran (CI) and the Dasht-e-Lut Basin [2]. At the longitude of CI, the overall Arabian-Eurasia convergence is moving roughly N–S at ~25-35 mm yr^{-1} [2]. Since the Arabian-Eurasia Euler pole lies in the Mediterranean region, the convergence rate increases with longitude, with values about 5-10 mm yr^{-1} higher in eastern Iran than in the west. Active deformation includes intercontinental shortening and thickening in most parts of the plateau and subduction of the oceanic crust of the Arabian plate under the Makran of southeast Iran [3]. In Iran, a destructive earthquake occurs every few years because it is situated over a seismic zone. Many destructive earthquakes in the last 50 years confirm the high seismicity of Iran. In the past three decades, only the Tabas earthquake of 1978, the Manjil earthquake of 1990, and the Bam earthquake of 2003 caused nearly 100,000 deaths [4].

Seismic hazard analysis transmits information on strong motions to allow for informed decisions on earthquake-resistant designs, and other societal impacts of earthquakes. The seismic hazard analysis can provide long-term probabilities of seismic event occurrence. The probabilistic approach to seismic hazard characterization is very compatible with current trends in earthquake engineering and the development of building codes, which have embraced the concept of performance-based design. The probabilistic seismic hazard analysis (PSHA) yields the annual frequency of exceedance of each different ground-motion level for each ground-motion parameter of interest. This relationship between ground-motion level and annual frequency of exceedance is called a ground-motion hazard curve.

Seismic analyses and the study of seismotectonic structure in Iran has been conducted in several previous studies [5-14]. Bozorgnia and Mohajer-Ashjai [7] studied the estimated peak ground acceleration (PGA) in major cities of Iran to determine various annual hazards. Nowroozi and Ahmadi [8] estimated level of hazard for different part of Iran. Ahmadi et al., [9] concluded that almost all the regions of Iran, with the exception of Esfahan-Sirjan, CI, and the ASAA region, have a high level of hazard for producing earthquakes with large PGA. Mirzaei et al., [10, 11] suggested a maximum possible magnitude of no less than $M_s = 7.8$ in the different regions of Iran. Tavakoli and Ghafory-Ashtiany [12] developed a seismic hazard map of Iran based on probabilistic seismic hazard computation. They estimated the contour levels of the PGA map range from 0.15 to 0.48 g for a return period of 475 years. Yazdani and Kowsari [14] used the Bayesian approach to calculate the probability that a certain cut-off magnitude would be exceeded at certain time intervals in different regions of Iran. In these studies, the earthquake catalogue in the concerned region has been gathered and processed, assuming that the earthquakes are independent events that occur randomly in time. The Iranian seismic code [15] has defined the design earthquake the ground motion with a 475-year return period as the motion “that will be exceeded with a 10% probability during an exposure time of 50 years”. In general, this return period is derived by assuming a Poisson process for ground motion occurrences, wherein the probability of an event is related to the annual frequency of exceedance of the ground motion and the exposure time. To asses this assumption, in this study different statistical distribution is used to model the recurrence times between ground motion events in similar regions with similar or different seismological characteristics (i.e., seismotectonic provinces).

2. SEISMOTECTONIC PROVINCES

The seismotectonic province is considered to be an area that under the present-day geodynamic regimes has a comparable tectonic setting and unified seismicity pattern [16]. Also, it can be defined as a geographic region of some geological, geophysical and seismological similarity with the assumption of uniform earthquake potential [12]. By considering these concepts the seismotectonic provinces of Iran was studied by several investigators. Stocklin [17], Takin [18], Berberian [19] and Mirzaei et al., [11] suggested simplified gross provinces, with a small number of divisions consisting of only nine, four, nine and five regions, respectively. More elaborate divisions, consisting of 23 and 20 seismotectonic provinces, were suggested by Nowroozi [5] and Tavakoli and Ghafory-Ashtiany [12]. For data mining and statistical study among seismic catalogs, it is important to note that among an active seismic area, there are different regions with different rates of seismicity. As a result, the density and number of events are not the same in different seismotectonic provinces. An appropriate method should be able to deal with such kind of data. Identification of the boundaries of the seismotectonic provinces in these investigations is the drawback of these methods. As a result, it is not reasonable to use hard divisions in identification of seismotectonic provinces. Mirzaei et al., [10, 11] delineated five major seismotectonic provinces in Iran, Zagros and Alborz–Azarbayejan, and for Central-East Iran, Kopeh Dagh and Makran, based on all available seismicity, geological and tectonic, as well as geophysical information (Figure 1).

Continental-continental collision zone of Zagros in southwest Iran is one the youngest and most active continental collision zone on the earth [20]. In the Zagros region of southwest Iran, most seismogenic structures are blind thrust faults [21]. A great number of earthquakes in highly seismic region of Zagros, occur on hidden faults. There is considerable uncertainty about their extent, geometry and the mechanism [11]. The highly seismic region of Iran is Alborz – Azarbayejan covering north and northwest of Iran. Jackson et al., [22] reported that reliable earthquake depths in the Alborz are above 15 km and that most focal mechanisms present left-lateral strike-slip motions along the faults parallel to the regional strike of the range and reverse faulting. This siesmotectonic province has experienced a severe seismicity during the last century. The continental collision zone of Kopeh-dagh in the northeast represents a northern segment of the Alpine-Himalayan orogenic belt. The characteristic of Kopeh-dagh seismic activity is the relative frequency of great earthquake with low depth.

The oceanic-continental subduction zone of Makran, where the consumption of oceanic crust of Arabian plate has occurred continuously since the early Cretaceous along a north dipping subduction zone underneath the Eurasia-Central Iranian microcontinent, covers the southeast of the Iran [11]. In Makran seismotectonic province there is no trustable evidence of seismic activity with medium depth and all the confirmed hypocenter depths are shallow.

Central-East Iran represents an interplate environment which is surrounded by the continental collision zone of Zagros from the west and southwest, the Alborz – Azarbayejan from the north, the continental collision zone of Kopeh-dagh from the northeast, from the southeast to oceanic-continental subduction zone of Makran and Helmand block from east. The Central Iranian Block is being compressed between two plates of greater rigidity, Arabia and Eurasia, and it is characterized by coherent plate motion with low-level internal deformation of less than 2 mm yr^{-1} [23]. The Central Iranian Block is characterized by discontinuous seismic activity with shallow, large magnitude earthquakes with apparent long recurrence periods [24].

3. SEISMIC CATALOGUE

The seismic assessment at the study site relied mainly on the catalogue of earthquakes and potential seismic sources that were compiled from available references containing historical andinstrumental events. The seismic catalogue of Iran can be divided into historical (pre-1900) and instrumental (post-1900) components. The

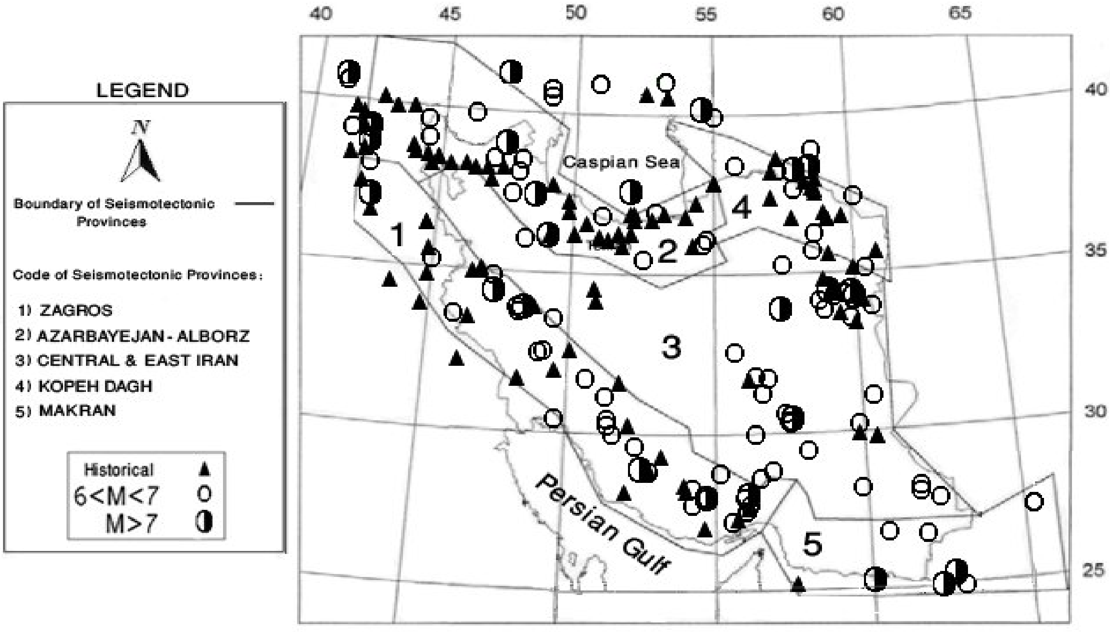
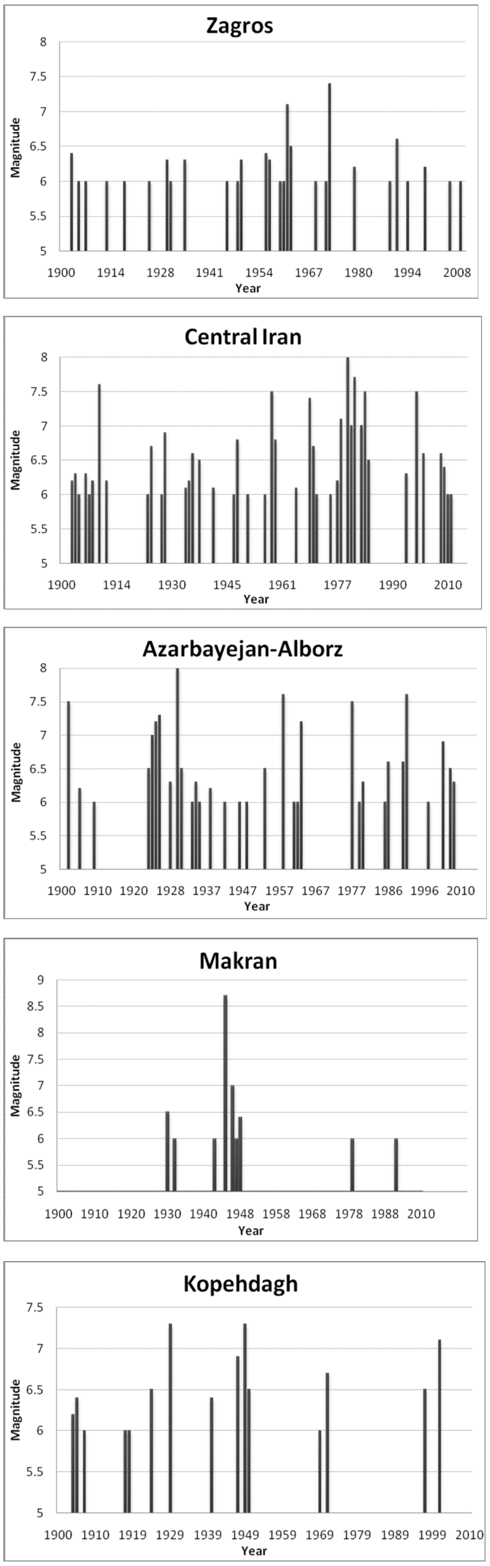


Figure 1. The epicenter location of historical and instrumental earthquake events (Ms ≥ 6.0). The border of different seismotectonic provinces are show

comprehensive study of Ambraseys [25] and other subsequent studies [3, 26, 27] noted the destructive historical earthquakes in Iran. Historical earthquakes had ascribed magnitudes that were computed based on a simple linear relationship between intensities and magnitudes. Early (pre-1964) and recent (post-1964) instrumentally recorded events were collected from Moinfar et al., [28], and the local and global seismological networks [29, 30]. Building and Housing Research Center developed the strong motion network, while it consists of more than 1110 accelerometric [31]. Many relocation analyses were performed on the instrumental component of the catalogue [5, 32-34]. There are two main difficulties using earthquake catalogue which is in great deal of inhomogeneity. The first is that the data are incomplete in terms of time and space and the second is the lack of uniform estimation of earthquake sizes and locations [35]. Historical magnitude inaccuracies are approximately 0.3 to 0.5 units [26, 27], and instrumental magnitude errors are usually considered to be less than 0.3 units [36]. The final collective catalogue in this study was prepared by eliminating aftershocks, foreshocks [37, 38] and incorrectly reported events from the data. The cleaned and updated catalogue contained earthquake magnitudes given in several scales. Body-wave magnitude (mb) and Richter local-magnitude scales were converted to the surface wave magnitude (Ms) according to the relationships proposed by IRCOLD [39]. The uncertainty of epicenter locations for historical events, early and recent instrumental earthquakes was assumed to be 20 km, 10 km and 5 km, respectively [21, 34].

Figure 1 shows the epicenter location of historical and instrumental events for Iran spanning the area between 24ºN to 40ºN and 44ºE to 62ºE. Figure 2 shows the available instrumental data for earthquakes in Iran with *Ms* ≥ 6.0 after the removal of the aftershock and foreshock earthquakes for different seismotectonic provinces. Only earthquakes greater than Ms 6, which are generally considered to be large enough to provide sever damage, have been used within the computations. The number of events (Table A1) is likely to be complete for this magnitude, while for greater magnitude is not sufficient. Uncertainty is usually considered by processing the recorded



Zagros

Central Iran

Azarbayejan-Alborz

Makran

Kopehdagh

Figure 2. Data with *Ms* ≥ 6.0 available from different seismotectonic provinces of Iran after the removal of the aftershock and foreshock

data, so the validity of stochastic models depends on the correctness and completeness of the applied data [40]. Table A1 shows the available instrumental data in different seismotectonic provinces with Ms ≥ 6.0 after the removal of the aftershock and foreshock earthquakes for statistical predictions.

4. METHODOLOGY

Earthquake could be regarded as discrete events, random character. It is quite natural to consider a sequence of earthquake events as a stochastic process. In most cases, when studying earthquake occurrence as a stochastic process, only times of events are considered. As they seem to occur randomly in time, the object has most often been to test whether real data support such an assumption. The sequence of seismic events to search for some relations between occurrence times, given information about size of the events, is modeled by a statistical distribution. The engineer often encounters problems where important information derives from the random occurrence of critical events during an extended period. Statistical studies show that earthquakes are clustered in both space and time. In general, there are two different problems, short- and long-term forecasting, and each involving different treatments of earthquake clustering. Because there is as yet no comprehensive model of earthquake occurrence, the long-term forecasting procedures are derived from a variety of statistical arguments. This prediction is essentially an empirical description of observed spatial clustering, and it has value only to the degree that it can estimate well the probabilities of future earthquakes. In general, it is assumed in a zero approximation that main events constitute a time-uniform Poisson process. That assumption is widely employed in seismic risk studies. Let $f(T)$ is the probability density function of the time intervals between earthquakes. From Bayes' theorem for conditional probabilities, the probability that an event A, given the knowledge of an event B, is simply the quotient of the probability of the event A without constraint and the probability of event B [41]:

$$P(A|B) = \frac{P(A)}{P(B)} \tag{1}$$

Applied to this problem, $P(A) = P(t + \Delta t)$ which is the probability that the next earthquake will occur at time Δt, from now. It is equal to the probability that at least one earthquake occurs between t and $t{+}\Delta t$:

$$P(A) = P(t \le T \le t + \Delta t) = \int_{t}^{t+\Delta t} f(T)dT \tag{2}$$

The probability that no earthquake occurs until time t and at least one occurs after time t, P(B) is equal to:

$$P(B) = P(T \ge t) = \int_{t}^{\infty} f(T)dT \tag{3}$$

The conditional probability that the earthquake will occur in the next interval (t, $t{+}\Delta t$), provide that it has not occurred in the elapsed time t since the last earthquake can be obtained:

$$P(\Delta t|t) = \frac{\int_{t}^{t+\Delta t} f(T)dT}{\int_{t}^{\infty} f(T)dT} \tag{4}$$

If earthquakes behaved in a purely periodic fashion, the conditional probability, $P(\Delta t|t)$, would always be unity. However, in Nature, significant stochastic fluctuations occur [42]. It is necessary to predict the time interval Δt for the occurrence of the next earthquake, given an observed elapsed time t since the last earthquake. Thus, the prediction of earthquake can be obtained by maximizing the conditional probability $P(\Delta t|t)$.

$$\frac{\partial}{\partial \Delta t} P(\Delta t|t) = 0 \tag{5}$$

Assuming reasonable models for the probability density of interval times between earthquakes and using Eq. (4) for the conditional probability of earthquake occurrence, it is necessary to determine probability density model that a large earthquake occurs during a future time intervals Δt, in a specific area. Here we discuss five different probability density models: (1) Exponential, (2) The Pareto power-law, (3) Lognormal, (4) The Rayleigh, and (5) Gamma. The mentioned procedure is used to compute the expected time to the next earthquake for different statistical distribution.

The properties of different statistical models are demonstrated in the previous studies [41 - 46]. Table 1 shows, in brief, five different used probability density models and their propertied. In this study, the procedure is applied to the instrumental seismic events in different seismotectonic provinces. The parameters of different statistical models for different seismotectonic provinces based on the recurrence time of before events, Table 2, are calculated.

Uncertainty is an essential and inescapable part of seismic hazard. To assess the degree of confidence of different probability density models, the square error can be calculated [47]:

$$\varepsilon^2 = \mathrm{E}[(\Delta t - \Delta\hat{t})^2] = \mathrm{Var}[\Delta t] + (\mu_{\Delta t} - \Delta\hat{t})] \qquad (6)$$

where Δt is the more probable time interval for the occurrence of the next large event in specific seismotectonic province. In this equation, E and Var are ensemble average and variance, respectively. This Also, to estimate the error, we need a sample of time intervals, Δt_i, determined by data of observed earthquake events in different seismotectonic provinces.

5. RESULTS AND DISCUSSION

In this study statistical analysis of the prediction of occurrence time of the next earthquake presented for different seismotectonic provinces of Iran (Zagros, Alborz–Azarbayejan, Central-East Iran, Kopeh Dagh, and Makran) by maximizing the conditional probability density of earthquake occurrence. Five different probability density

TABLE 1. The used different probability density models and their properties

Type	Probability density models ($f(T)$)	Mean	Probable time interval ($\frac{\partial}{\partial \Delta t} P(\Delta t \| t) = 0$)	Description
Exponential	$\frac{1}{\mu}\exp(-\frac{T}{\mu})$	μ	$\Delta\hat{t} = \mu$	.μ is the parameter of the Exp. distribution
Pareto	$\alpha\beta^{\alpha}T^{-(\alpha+1)}$	$\alpha\beta/(\alpha-1)$	$\Delta\hat{t} = \frac{1}{\alpha+1}$	.α and β are power-law variables
Lognormal	$\frac{\exp(-(\ln T-\bar{X}))^{\frac{2}{2\sigma_X^2}}}{T\sigma_X\sqrt{2\pi}}$	$\exp(\bar{X}+\sigma_x^2/2)$	$\ln\Delta\hat{t} = \bar{X}-\sigma_X^2$	X and σ_X are the lognormal paremeters
Rayleigh	$\frac{t}{\eta^2}\exp(-\frac{T^2}{2\eta^2})$	$\eta\sqrt{\pi/2}$	$\Delta\hat{t} = -t \pm \sqrt{t+2\eta^2}$	η is variable parameter
Gama	$\frac{\gamma^{\alpha}\tau^{\alpha-1}e^{-\gamma\tau}}{\Gamma(\alpha)}$	α/γ^2	$\Delta\hat{t} = \frac{\alpha-1}{\gamma}$	α and γ are Gama parameters

TABLE 2. The parameters of different probability density models in different seismotectonic provinces of Iran.

Type	Alborz-Azarbayejan	Zagros	Kopeh Dagh	Central & East Iran	Makran
Exponential; μ	9.1	5.51	15.96	6.65	26.7
Pareto; α	2.26	2.39	2.11	2.32	2.06
β	1.73	2.208	3.41	1.36	3.48
Lognormal; X	0.734	1.07	1.44	0.46	1.32
σ_X	0.889	1.94	0.922	0.90	1.08
Rayleigh; η	2.47	3.02	5.17	1.91	5.38
Gama; α	0.826	1.49	0.744	0.784	0.449
γ	0.26	0.394	0.115	0.328	0.066

models, Exponential, The Pareto power-law, Lognormal, The Rayleigh, and Gamma, are studied for the observed distribution of recurrence times in these seismotectonic provinces. The analytical results for different probability density models are summarized in Table 3. These results showed the recurrence time, time of predicted next event, and the error of different distribution for instrumental (after 1900) earthquake events. Results of this study indicated Exponential and Pareto estimations seem to be better than other estimations in prediction of occurrence time of the next earthquake in different seismotectonic provinces, and the term of error in Exponential distribution is less than Pareto distribution.

Table 4 showed the comparison of predicted

TABLE 3. Prediction of the earthquake events in different seismotectonic provinces

Models	Alborz-Azarbayejan	Zagros	Kopeh Dagh	Central & East Iran	Makran
Exponential	$\Delta t=9.1$ 2013.6 $\varepsilon = \pm 0.067$	$\Delta t=5.51$ 2014.29 $\varepsilon=\pm 0.24$	$\Delta t=15.96$ 2016.98 $\varepsilon= \pm 2.7$	$\Delta t=6.65$ 2012.89 $\varepsilon= \pm 0.106$	$\Delta t=26.7$ 2017.25 $\varepsilon= \pm 2.99$
Pareto	$\Delta t=7.84$ 2012.34 $\varepsilon= \pm 0.76$	$\Delta t=2.23$ 2011.01 $\varepsilon= \pm 1.56$	$\Delta t=12.52$ 2013.54 $\varepsilon= \pm 3.84$	$\Delta t=5.53$ 2011.78 $\varepsilon= \pm 1.19$	$\Delta t=26.46$ 2017.01 $\varepsilon= \pm 2.08$
Lognormal	$\Delta t=0.94$ 2005.43 $\varepsilon = \pm 2.19$	$\Delta t=1.76$ 2010.53 $\varepsilon= \pm 1.86$	$\Delta t=1.80$ 2002.82 $\varepsilon= \pm 2.33$	$\Delta t=0.67$ 2006.94 $\varepsilon= \pm 1.7$	$\Delta t=1.16$ 1991.71 $\varepsilon= \pm 3.77$
Rayleigh	$\Delta t=4.27$ 2008.76 $\varepsilon= \pm 4.87$	$\Delta t=4.47$ 2013.25 $\varepsilon= \pm 0.88$	$\Delta t=7.93$ 2008.45 $\varepsilon= \pm 5.57$	$\Delta t=3.39$ 2009.64 $\varepsilon= \pm 3.25$	$\Delta t=8.83$ 1999.38 $\varepsilon= \pm 15.66$
Gama	$\Delta t=-0.65$ 2003.84 $\varepsilon= \pm 3.79$	$\Delta t=1.25$ 2010.03 $\varepsilon= \pm 2.37$	$\Delta t=-2.22$ 1998.97 $\varepsilon= \pm 6.23$	$\Delta t=-0.65$ 2005.59 $\varepsilon= \pm 3.04$	$\Delta t=-8.27$ 1982.26 $\varepsilon= \pm 12.84$

Δt = recurrence time; ε = error

TABLE 4. Comparison of predicted earthquake events with the observed events in different seismotectonic provinces

Seismotectonic provinces	Before observed event	Predicted next event	Next observed event
Zagros	1990.84 (6 Nov., 1990)	1994.42 ($\Delta t = 3.58$, $\varepsilon = \pm 0.23$)	1994.17 (1 Mar., 1994)
	1968.70 (14 Sep., 1968)	1972.18 ($\Delta t = 3.48$, $\varepsilon = \pm 0.48$)	1971.85 (8 Nov., 1971)
	1956.82 (31 Oct., 1956)	1960.70 ($\Delta t = 3.87$, $\varepsilon = \pm 0.41$)	1960.15 (24 Feb., 1960)
Alborz–Azarbayejan	1997.17 (28 Feb., 1997)	2000.75 ($\Delta t = 3.61$, $\varepsilon = \pm 0.18$)	2000.90 (25 Nov., 2000)
	1986.18 (6 Mar., 1986)	1989.49 ($\Delta t = 3.30$, $\varepsilon = \pm 0.32$)	1989.70 (16 Sep., 1989)
	1957.51 (2 Jul., 1957)	1960.41 ($\Delta t = 2.91$, $\varepsilon = \pm 0.85$)	1960.89 (25 Nov., 1960)
Central-East Iran	1999.18 (4 Mar., 2009)	2003.90 ($\Delta t = 4.72$, $\varepsilon = \pm 0.13$)	2003.98 (26 Dec., 2003)
	1964.98 (22 Dec., 1964)	1968.53 ($\Delta t = 3.57$, $\varepsilon = \pm 0.28$)	1968.66 (31 Aug., 1968)
	1955.93 (4 Dec., 1955)	1958.12 ($\Delta t = 2.20$, $\varepsilon = \pm 0.29$)	1957.94 (13 Dec. 1957)
Kopeh Dagh	1940.35 (4 May, 1940)	1946.41 ($\Delta t = 6.07$, $\varepsilon = \pm 0.97$)	1946.83 (4 Nov., 1946)
	1923.71 (17 Sep., 1923)	1929.27 ($\Delta t = 5.56$, $\varepsilon = \pm 0.33$)	1929.34 (1 May, 1929)
Makran	1979.03 (10 Jan., 1979)	1990.54 ($\Delta t =11.51$, $\varepsilon = \pm 1.51$)	1990.46 (17 June, 1990)

some different earthquake events based on Exponential distribution with the observed ones. In these events, the error of the time of next earthquake by Exponential distribution is acceptable. These results indicate that Exponential model can predict the recurrence time of large ground motion event in different seismotectonic provinces of Iran.

The Exponential distribution, which is the familiar case of Poissonian statistics, is memory-less and the expected time until the next event is independent of previous observations and of the elapsed time since the last earthquake. It was found that the Poisson model is adequate assumption in seismic hazard analysis in different part of Iran, since the time since the last earthquake has no influence on the time of the next earthquake event in different seismotectonic provinces.

6. ACKNOWLEDGMENT

The authors would like to thank anonymous reviewers for comments which helped to improve the manuscript.

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APPENDIX

TABLE A1. Instrumentally earthquake events in different seismotectonic provinces

Alborz & Azarbayejan

Year	Month	Day	Occ. time	Rec. time	Lat.	Lon.	Ms	Ref.
1902	2	13	1902.118	0.000	40.72	48.6	7.5	MOI
1905	1	9	1905.025	2.907	37	48.68	6.2	MOI
1908	9	28	1908.734	3.710	38	44	6	MOI
1923	9	17	1923.704	14.970	35.5	55	6.5	ISC
1924	2	19	1924.134	0.430	38.59	48.5	7	MOI
1924	9	13	1924.693	0.559	38.66	44	7.2	MOI
1925	1	9	1925.025	0.332	40.74	43.28	7.3	MOI
1927	7	22	1927.553	2.529	34.9	52.9	6.3	MOI
1930	5	6	1930.345	2.792	37	44	7.2	ISC
1931	4	27	1931.321	0.975	39.34	45.97	6.5	MOI
1934	2	22	1934.142	2.822	38.76	45.94	6	MOI
1935	4	11	1935.277	1.134	36.3	53.5	6.8	ISC
1935	5	1	1935.332	0.055	40.4	42.4	6	ISC
1938	2	14	1938.121	2.789	40.39	53.68	6.2	MOI
1941	9	10	1941.685	3.564	39.5	43.0	6	ISC
1945	9	1	1945.66	3.975	39	43.3	6	MOI
1947	12	14	1947.942	2.282	37.9	43.1	6	MOI
1953	2	12	1953.115	5.173	35.39	54.88	6.5	MOI
1957	7	2	1957.499	4.384	37	52.5	7.4	ISC
1960	11	25	1960.890	3.392	39.5	47.5	6	MOI
1961	6	9	1961.436	0.545	40	50	6	MOI
1962	9	1	1962.66	1.225	35.71	49.81	7.2	MOI
1976	11	24	1976.888	14.227	39.12	44.03	7.5	MOI
1978	11	4	1978.833	1.945	37.67	48.9	6.1	ISC
1980	5	4	1980.340	1.507	38.05	48.99	6.3	MOI
1985	10	29	1985.819	5.479	36.68	54.75	6	MOI
1986	3	6	1986.181	0.362	40.37	51.56	6.6	MOI
1989	9	16	1989.701	3.521	40.27	51.66	6.2	ISC
1990	6	20	1990.466	0.764	36.96	49.3	7.4	ISC
1997	2	28	1997.159	6.693	38.07	48.05	6	ISC
2000	11	25	2000.89	3.732	40.23	49.95	6.4	BHRC
2002	6	22	2002.471	1.581	35.67	48.93	6.4	BHRC
2004	5	28	2004.405	1.934	36.29	50.87	6.3	ISC

Zagros

Year	Month	Day	Occ. time	Rec. time	Lat.	Lon.	Ms	Ref.
1902	7	9	1902.518	0.000	27.08	56.34	6.4	MOI
1905	4	25	1905.315	2.797	27.67	56.03	6	MOI
1907	3	31	1907.249	1.934	30	50	6	MOI
1913	3	24	1913.23	5.981	26.8	53.7	6	MOI
1917	7	15	1917.534	4.304	30.37	48.86	6	MOI
1924	6	30	1924.493	6.959	27.5	53.8	6	MOI
1929	7	15	1929.534	5.041	32.0	49.50	6.2	ISC
1930	5	11	1930.359	0.825	27.5	55	6	MOI
1934	2	4	1934.093	3.734	30.65	51.64	6.3	MOI
1946	3	12	1946.197	12.104	29.79	51.72	6	MOI
1948	7	5	1948.507	2.310	29.88	57.73	6	MOI
1949	4	24	1949.312	0.805	27.28	56.46	6.3	MOI
1956	2	3	1956.09	6.778	33.29	46.7	6.4	MOI
1956	10	31	1956.825	0.734	27.25	54.5	6.8	ISC

1960	2	24	1960.148	3.323	31.25	51	6	MOI
1960	4	24	1960.312	0.164	27.7	54.38	6	ISC
1960	8	1	1960.578	0.266	27.5	55	7.0	ISC
1961	6	11	1961.441	0.863	27.78	54.51	6.5	MOI
1968	9	14	1968.696	7.255	28.3	53.1	6	MOI
1971	11	8	1971.844	3.148	27.1	54.6	6.1	ISC
1972	4	10	1972.274	0.430	28.43	52.79	7.4	MOI
1978	12	14	1978.942	6.668	32.13	49.64	6.2	ISC
1988	8	11	1988.605	9.663	29.97	51.68	6	MOI
1990	11	6	1990.838	2.233	28.24	55.46	6.6	ISC
1994	3	1	1994.167	3.329	29.1	52.69	6.1	ISC
1999	5	6	1999.345	5.178	29.5	51.88	6.3	ISC
2006	3	31	2006.249	6.904	33.48	48.86	6	BHRC
2008	9	10	2008.685	2.436	26.83	55.81	6	BHRC

Central& East Iran

Year	Month	Day	Occ. time	Rec. time	Lat.	Lon.	Ms	Ref.
1903	3	22	1903.225	0.000	33.16	59.71	6.2	MOI
1903	3	22	1903.225	0.000	31.3	56.6	6.3	MOI
1903	3	22	1903.225	0.000	35	60	6	MOI
1905	1	9	1905.025	1.800	33.1	50	6.3	MOI
1905	6	19	1905.463	0.438	29.89	59.98	6	MOI
1907	3	29	1907.244	1.781	34.7	60.2	6.2	MOI
1909	1	23	1909.063	1.819	33.5	49	7.6	MOI
1911	4	18	1911.296	2.233	31.23	57.03	6.2	MOI
1923	5	25	1923.397	12.101	35.19	59.11	6	MOI
1923	9	22	1923.718	0.321	29.51	56.63	6.7	MOI
1927	5	9	1927.353	3.636	27.5	56.0	6.2	ISC
1927	7	7	1927.512	0.159	28	62	6.9	MOI
1933	10	5	1933.753	6.241	34.76	57.45	6.1	MOI
1933	11	28	1933.899	0.145	32.01	55.94	6.2	MOI
1934	6	13	1934.447	0.548	27.5	62.5	7	ISC
1936	6	30	1936.493	2.047	33.54	60.41	6.5	MOI
1941	2	16	1941.126	4.633	33.3	58.7	6.2	ISC
1946	8	17	1946.622	5.496	35	46	6	MOI
1947	9	23	1947.721	1.099	33.3	58.7	6.8	ISC
1950	9	24	1950.723	3.003	34.5	60.7	6	MOI
1955	12	4	1955.915	5.192	33.37	48.8	6	MOI
1957	12	13	1957.94	2.025	34	48	7.2	ISC
1958	8	16	1958.619	0.679	34.5	48	6.8	MOI
1964	12	22	1964.964	6.345	28.12	56.8	6.1	MOI
1968	8	31	1968.660	3.696	34.02	58.96	7.4	MOI
1969	11	7	1969.841	1.181	27.9	60.1	6.7	MOI
1971	4	12	1971.279	1.438	28.3	55.6	6	MOI
1975	3	7	1975.184	3.904	27.5	56.26	6	MOI
1976	11	7	1976.841	1.658	33.8	59.15	6.2	ISC
1977	3	21	1977.222	0.381	27.61	56.39	7.1	MOI
1978	9	16	1978.701	1.479	33.39	57.43	8	MOI
1979	1	16	1979.044	0.342	32	59	7	ISC
1979	11	27	1979.896	0.852	33.96	59.73	7.5	ISC
1981	6	11	1981.441	1.545	29.91	57.71	6.9	ISC
1981	7	28	1981.570	0.129	30.01	57.79	7.3	ISC
1983	4	18	1983.296	1.726	27.79	62.05	6.5	MOI
1994	2	24	1994.148	10.852	30.79	60.51	6	ISC
1997	5	10	1997.356	3.208	33.82	59.8	7.5	ISC
1999	3	4	1999.175	1.819	28.34	57.19	6.4	ISC

2003	12	26	2003.975	4.800	29	58.3	6.8	ISC
2005	2	22	2005.142	1.167	30.74	56.83	6.4	ISC
2005	3	13	2005.200	0.058	27.15	61.88	6	BHRC
2006	2	28	2006.243	0.959	33.69	49.04	6	BHRC

Kopehdagh

Year	Month	Day	Occ. time	Rec. time	Lat.	Lon.	Ms	Ref.
1903	9	25	1903.726	0.000	35.23	58.45	6.2	MOI
1904	11	9	1904.847	1.121	36.94	59.77	6.4	MOI
1907	4	17	1907.293	2.447	37.74	57.85	6	MOI
1917	11	28	1917.899	10.605	37.18	57.88	6	MOI
1918	3	24	1918.230	0.332	35.08	60.69	6	MOI
1923	9	17	1923.704	5.474	37.7	57.3	6.5	MOI
1929	5	1	1929.332	5.627	38	58	7.1	ISC
1940	5	4	1940.340	11.008	35.76	58.53	6.4	MOI
1946	11	4	1946.833	6.493	39.32	55.2	6.9	MOI
1948	10	5	1948.753	1.921	37.9	58.6	7.3	ISC
1950	5	9	1950.353	1.600	38.34	58.41	6.5	MOI
1969	1	3	1969.008	18.655	37.1	57.8	6	ISC
1970	7	30	1970.575	1.567	37.85	55.94	6.7	ISC
1997	2	4	1997.093	26.518	37.66	57.29	6.6	ISC
2000	12	6	2000.921	3.827	39.57	54.8	7.1	ISC

Makran

Year	Month	Day	Occ. time	Rec. time	Lat.	Lon.	Ms	Ref.
1929	9	3	1929.666	0.000	26.5	62.25	6.5	ISC
1932	4	18	1932.296	2.630	25	64	6	ISC
1943	2	6	1943.099	10.803	24.89	63.25	6	MOI
1945	11	27	1945.896	2.797	24.9	62.8	8.7	MOI
1947	8	5	1947.589	1.693	25.5	63	7.1	ISC
1947	10	3	1947.748	0.159	26	57.2	6.2	ISC
1948	1	30	1948.082	0.334	24.9	63.5	6.4	MOI
1979	1	10	1979.027	30.945	26.5	60.97	6	ISC
1990	6	17	1990.458	11.430	27.4	65.72	6	MOI

MOI: Moinfar et al., 1994 [28]; BHRC: Building and Housing Research Center [29]; ISC: On-line Bulletin [30]