28 May 2010, 2:00 pm - 3:30 pm

Evaluating Seismicity Parameters of Sanandaj, Iran Based on Instrumental Earthquakes

Kaveh Andisheh
University of Kurdistan, Iran

Gholamreza Ghodrati Amiri
Iran University of Science and Technology, Iran

Motaza Taghizadeh
Saqhez Center of Education of Applied Science, Iran


Fifth International Conference on
Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics
and Symposium in Honor of Professor I.M. Idriss
May 24-29, 2010 • San Diego, California

EVALUATING SEISMICITY PARAMETERS OF SANANDAJ, IRAN BASED ON INSTRUMENTAL EARTHQUAKES

Kaveh Andisheh
Lecturer of college of civil engineering,
university of Kurdistan, Sanandaj, Iran

Gholamreza Ghodrati Amiri
Proffesor, school of civil engineering,
Iran university of science and technology,
Tehran, Iran

Motaza Taghizadeh
Lecturer of college of engineering
Saqhez center of education of applied
science, saqhez, Iran

ABSTRACT

The main goal of this paper is to evaluate the seismic parameters of Sanandaj, Iran. For this reason, at first, all the occurred instrumental earthquakes (1900-2006) in a radius of 200 km of Sanandaj city have been gathered. After elimination of the aftershocks and foreshocks, the main earthquakes were taken into consideration to calculate the seismic parameters by Gutenberg-Richter method, cumulative distribution functions, and Kijko-Sellevoll approach. This paper aims at estimation of seismicity parameters based on the seismic events and the relation between the cumulative frequency of earthquake occurrence and its magnitude. For this purpose the variable windows in time and location domains are employed, and the earthquakes are supposed to follow Poisson's formulation. Subsequently, the seismicity coefficients for Gutenberg–Richter, cumulative distribution functions, and Kijko–Sellevoll methods are calculated and the magnitude–period graphs are constructed. These results serve to illustrate the need to carefully reassess the reliability of seismicity parameters using them for seismology, or seismic-hazard purposes.

INTRODUCTION

Iran is one of the most seismically active areas in the world. This activity primarily results from its position as a 1000-km-wide zone of compression between the colliding Eurasian and Arabian continents.[Engdahl E. R et al. 2006]

The studied region encircles Sanandaj city with the radius of 200 km. Sanandaj, the administrative centre of Kurdistan province in Iran, is located in Zagros region. According to the resent studies The Zagros mountains form a linear intra-continental fold-and-thrust belt trending NW–SE between the Arabian shield and central Iran (Fig. 1). It is one of the most seismically active belts in Asia today, with frequent earthquakes of up to Ms 7.0. With its high level of seismicity, together with its apparent structural simplicity and geological youth, the Zagros has been influential in studies of continental shortening. It is extremely rare for coseismic surface faulting to be associated with Zagros earthquakes, so the most accessible information relating to active faulting comes from earthquake seismology. [Talebian M. and Jackson J. 2004] Sanandaj city is situated near the faults which are along the Zagros faults. Occurrence of several earthquakes in recent years [especially since 2000] proves that the faults of Zagros have been activated.

The studied region has high level of seismicity and the seismicity parameters are the importance parameters to analyze and predict the strong ground motion, so the importance of this research is obvious.

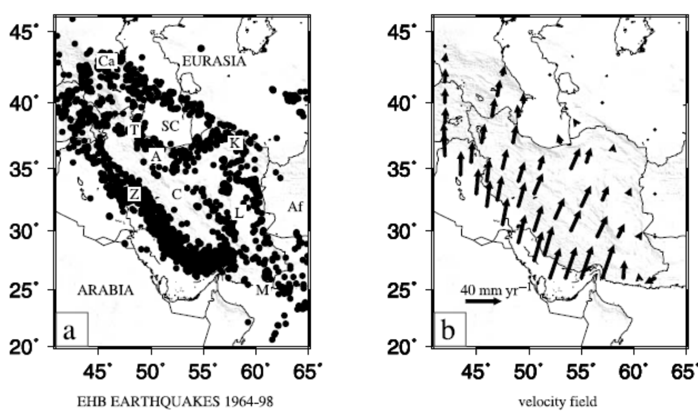

Fig.1. (a)Seismicity of Iran1964-98, with epicenters from the catalogue of Engdahl et al.(1998). The Zagros is marked by Z. (b) A velocity field showing how northward motion of Arabia relative to Asia is absorbed in Iran. [Talebian M. and Jackson J. 2004]

GEOLOGIC BACKGROUND

Based on geological and geotectonical references, Sanandaj is situated in the zone of Sanandaj-Sirjan band [as an independent region of the central Iran] and also located near to the zone of high Zagros.

According to geological studies, Sanandaj-Sirjan zone is the most active tectonic zone in Iran. The zone is influenced by the Mesozoic tectonic occurrences and severe foldings, faultings and Magmatism have been caused. But Cenozoic era appears as erosion without folding in the zone. In fact severe faulting and relative erosion caused in Mesozoic tectonic occurrences in Sanandaj-Sirjan zone have saved it from getting buried under Cenozoic deposits. Only so me shale and sandstone appearances are seen in small areas in west and east of Khomein located in the low parts of Sanandaj-Sirjan band. These are the youngest deposits of this zone. Besides, driving the oceanic crust of the high Zagros under the south active edge of central Iran (Sanandaj-Sirjan belt) has caused a Magmatic belt during Mesozoic and possibly tertiary. The Arabian plateau movement towards north and the subduction of its oceanic crust has closed the Alps Ocean of the high Zagros and finally has caused the collision of the central Iran and the Arabian plateau[Berberian, M., et. al, 1981]. On the basis of the available information the thickest part of the crust is situated along Sanandaj-Sirjan (south west of the continental side of central Iran during Mesozoic) and also in the north east part of this zone (the continental side of Paleozoic and near Kopeh Dagh belt). The studied region is situated in the collided area of Iran, Arabia and Caucasus and is involved in motions which are caused by the transaction of these areas. Hence, it has unique seismotectonic specifications [Hesami, K., et. al, 2001; Berberian, M., 1981].

MODEL OF SEISMOTECHTONIC OF SANANDAJ CITY

Based on seismotectonic, the studied region contains the seismotectonic units of Maraghe-Sirjan (including two tectonic zones: Sanandaj-Sirjan and Oroumiye-Dokhtar in the middle of Zagros and central Iran), the high Zagros, the driven folded thrust of Zagros and Central Alborz.

Based on the performed studies, the studied region, a part of Zagros, is situated in the collided part of Iran, Arabia and Caucasus and mainly has got involved in vertical strike-slip and transitional motions. Structural elements of studied region consist of faults with north-west; south-east direction and reverse strike-slip reverse mechanism. Vertical component along these structures is mainly reversed (compressive) [Harvard Seismology education, 2007; Hesami, K., et. al, 2001; Berberian, M., 1981]. Release rate analysis of seismic moment of earthquakes in the studied region shows that main part of energy releases along the strike-slip moving faults. But this is incompatible with the expected shortening of the region. So, this is the fact that increases the probability of moderate and severe earthquakes [Tchalenko, J. S., et. al, 1974]. Most of the past earthquakes in the region were those have small depth and in many cases the bedrock is involved in deformations. The mean Moho depth is about 50 km and the depth of the seismic stratum has been assessed 8-12 km. [Maggi, A., et. al, 2002], According to focal mechanism of past earthquakes and tectonic evidences, the mechanisms of the reverse faults are predominant in the studied region but the effect of the reverse strike-slip faults can't be ignored. Groups of young faults of Zagros as reverse strike-slip faults are most active faults of the region which encircle its young and principal deformations.

Fig.2 displays the centroid depth determined from body wave modeling. These vary from 4 to 20 km, with typical uncertainties being ± 4 km.

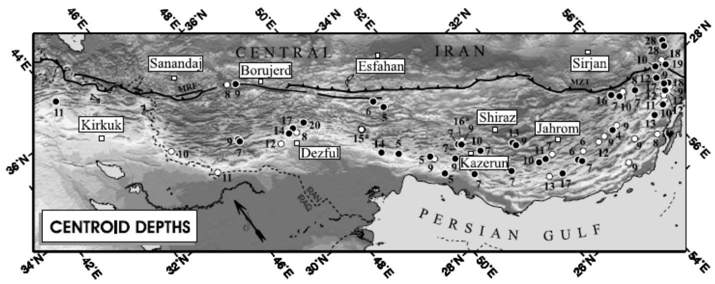

Fig.2. Earthquake centroid depths determined from body wave modeling. Numbers are depth in km. block circles are those determined from long period P and SH waves. Open circles are those determined from P waves alone. The two depths marked with stars (15 and 16*) are earthquakes whose depths were estimated from SH wave alone (Talebian M. and Jackson J. 2004).*

Earthquake Data

In this paper a list of earthquakes containing instrumental events and covering the period from 1900 to 2006 is used. The most severe earthquake of the region has occurred in the south of Sahneh with the magnitude of mb7.2 [Moinfar, A., et. al, 1994]. The earthquake occurred on December 13, 1957 in the region of Farsinj and is known as Farsineh earthquake. According to official reports 1130 people died and 211 villages were destroyed.

Since all magnitudes reported for historical earthquakes are in the form of surface wave, *Ms*, also instrumental earthquakes are based on surface wave, *Ms*, or volumetric wave (m_b). Then, the magnitude of the surface wave, *Ms*, is used for all data. Using the relationship presented by Iranian Committee of Large Dams [IRCOLD, 1994], the magnitude of m_b is converted into *Ms*. In seismic hazard analysis of a region it is assumed that occurred earthquakes are location and time independents. Regarding the mentioned limitations, foreshocks and aftershocks that are related to principal earthquakes should be eliminated from the data base. In this study Gardner and Knopoff [Gardner, J.K., et. al, 1974] method is used to eliminate aftershocks and foreshocks. Fig.3 shows distribution of peak magnitude of instrumental earthquakes in a 200 Km radius of Sanandaj city after elimination foreshocks and aftershocks. Fig.4 and Fig.5 represent the time distribution for instrumental earthquakes occurred in a 200 km radius of Sanandaj city. According to statistical analysis of instrumental earthquakes (from 1900 till 2006) in the region, 16% of earthquakes have magnitude greater than 5 (Ms>5.0) and 84% of them are less than 5 (Ms<5.0).

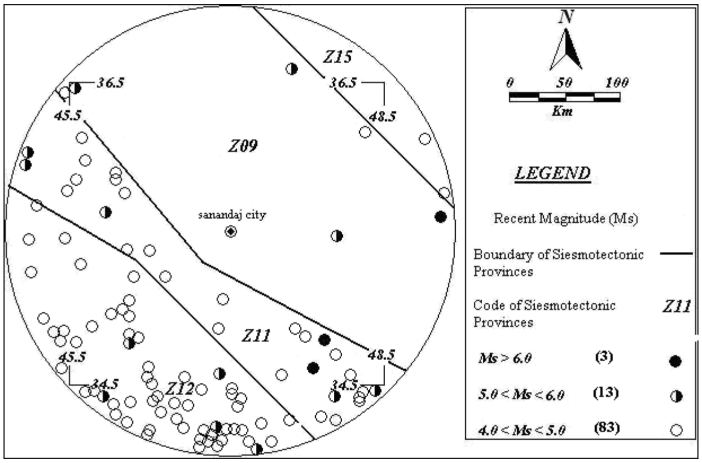

Fig.3. The distribution of magnitude of instrumental earthquakes in a 200 Km radius of Sanandaj city [Ghorati Amiri, G., Andisheh, K., and Razavyan Amrei. A. 2009]

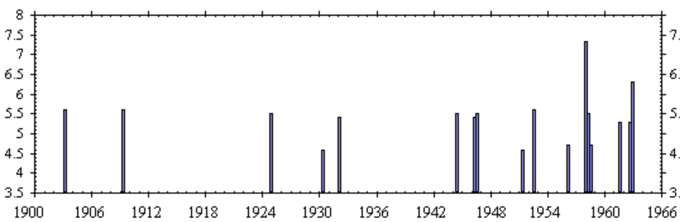

Fig.4. Time distribution of peak magnitude of instrumental earthquakes (1900 – 1964) in a 200 Km radius of Sanandaj city [Ghorati Amiri, G., Andisheh, K., and Razavyan Amrei. A. 2009]

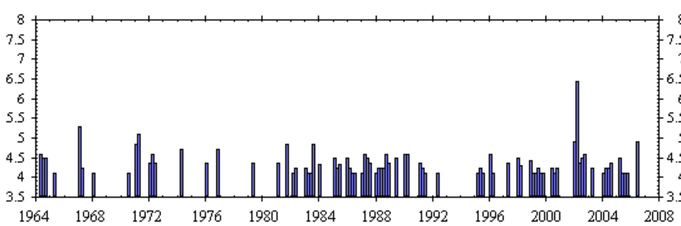

Fig.5. Time distribution of peak magnitude of instrumental earthquakes (1964 – 2006) in a 200 Km radius of Sanandaj city [Ghorati Amiri, G., Andisheh, K., and Razavyan Amrei. A. 2009]

EVALUATION OF SEISMICITY PARAMETERS

In this paper, earthquake hazard parameters such as, maximum expected magnitude, *Mmax*, the rate of earthquake occurrence with different magnitudes (activity rate), λ, and b have been evaluated using maximum likelihood method [Kijko, A., and Sellevoll, M.A., 1992], [Kijko, A., 2000], Gutenberg-Richter method, and Gumbel Cumulative Distribution Functions. Besides, the return period and the occurrence probability of each magnitude have also been calculated by these used methods. For these purposes, for all used methods, at first, all the occurred earthquakes in a radius of 200 km of Sanandaj city have been gathered. foreshocks and aftershocks that are related to principal earthquakes should be eliminated from the data base. After elimination of the aftershocks and foreshocks, the main earthquakes were taken into consideration to calculate the seismic parameters by linear regression method.

Evaluation of Seismicity Parameters using Kijko Method

The seismicity parameters for Sanandaj is evaluated by Kioko method. Kijko method is based on double truncated Gutenberg-Richter distribution function and the Maximum Likelihood estimation method.

In this paper two different categories of earthquakes are taken into consideration:

- Inaccurate instrumental earthquakes (1900-1963) with the magnitude error of 0.2 (the first time period).
- accurate instrumental earthquakes (1964-2006) with the magnitude error of 0.1 (the second time period)

The calculation results of the seismic hazard parameters for instrumental earthquakes data are represented in Table 1 [Ghorati Amiri, G., Andisheh, K., and Razavyan Amrei. A. 2009].

Table 1: The result values of the calculated seismic hazard parameters for Sanadaj using instrumental earthquakes data by Kijko method [Ghorati Amiri, G., Andisheh, K., and Razavyan Amrei. A. 2009]

Catalogue	Parameter	Value	Data Contribution to the Parameters (%)		
			Period#1	Period#2	Period#3
Instrumental Earthquakes Data	Beta	2.03		23.4	76.6
	Lambda(for Ms=4)	1.08		17.2	82.8

Evaluation of Seismicity Parameters using Gutenberg-Richter Method

In cases, earthquake recurrence is expressed by Gutenberg-Richter b-line. A recurrence model specifies the relative number of earthquakes of different magnitude levels. The equation 1 shows Gutenberg-Richter relationship [Gutenberg, B., and Richter C.F., [1954].

$$\text{Log } N = a - bM \qquad (1)$$

Where M= magnitude; N= expected (or average) number of earthquakes of magnitude greater than or equal M; a and b are seismicity parameters that are constants for a given source. This relationship plots as a straight line with a y-intercept of "a" and slope of "b", that M is a variable, hence the name b-line.

Multiple values of "a" and "b" can be used to represent different portions of the magnitude scale of a given source. The line can be driven from regression analysis of either recorded data or a combination of recorded and geologic data, with the latter usually resulting in multi-sloped b-line.

The calculating results of seismicity parameters using regression analysis method are represented in Fig. 4. The results show a=4.4494, and b=0.6363 for Sanandaj.

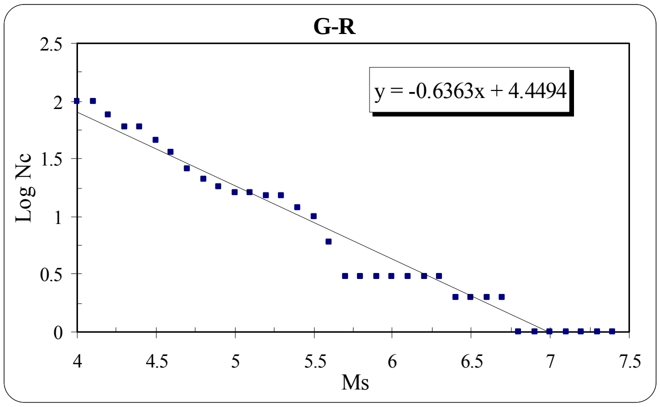

Fig.4. The calculating of seismicity parameters of Sanadaj using Gutenberg-Richter Method

Evaluation of Seismicity Parameters using Gumbel Cumulative Distribution Functions

The seismicty patameters can be evaluated by three types of Gumbel Cumulative Distribution Functions containing type I [GUMBEL E. J 1958], type III [GUMBEL E. J 1958], and type S [HOWELL B. F.1980]. In order to calculate seismicity parameters using Gumbel Functions, the main earthquakes were taken into consideration to calculate the seismic parameters by regression analysis method when the effects of aftershocks and foreshocks are avoided. The equations 2 to 4 show Gumbel Functions type I, III, and S respectively.

$$P(M \le Mi) = q = \exp\{-C\exp[B(-Mi)]\} \qquad (2)$$

$$P(M \le Mi) = q = \exp\{-C\exp[B\ln(M\max - Mi)]\} \qquad (3)$$

$$P(M \le Mi) = q = \exp\left\{-C\exp\left[0.5B\ln\left(\frac{M\max - 2Ma + Mi}{M\max - Mi}\right)\right]\right\} \qquad (4)$$

The equations 1 to 3 can be shown as equations 5 to 7 respectively. Each of the following relations is demonstrated in the form $y = \lambda x + \delta$ that $\ln(-\ln q) = y$, $\ln C = \delta$, $B = \lambda$, and x is a function according to M.

$$\ln(-\ln q) = \ln C + B(-Mi) \qquad (5)$$

$$\ln(-\ln q) = \ln C + B\ln(M\max - Mi) \qquad (6)$$

$$\ln(-\ln q) = \ln C + B[0.5\ln(\frac{M\max - 2Ma + Mi}{M\max - Mi})] \qquad (7)$$

Gumbel Cumulative Distribution Function type I. the Gumbel Function type I was shown in equation 2 and equation 5. In the first type of cumulative function (Type I) the magnitude domain is infinite, while there are no earthquakes with the minimum and the maximum magnitude. The line, relating to Gumbel Function type I, can be driven from regression analysis of recorded data and C and B, represented in equations 2 and 5, can be determined from the results. The Fig. 5 shows B=1.2845, C= $e^{5.2189}$ using Gumbel Function type I.

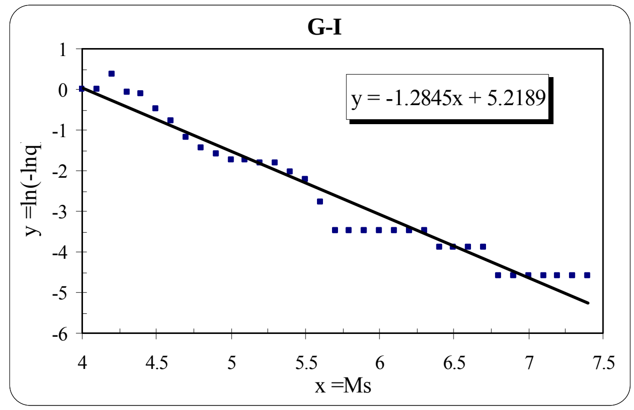

Fig.5. The calculating of seismicity parameters of Sanadaj using Gumbel Cumulative Distribution type I Function

Gumbel Cumulative Distribution Function type III. the Gumbel Function type III was shown in equation 3 and equation 6. In the third type of function (Type III) the upper bound is considered as Mmax. In accordance with the previous study for Sanandaj the upper boundary limit is 7.7 (M_{max} = 7.7) [Ghorati Amiri, G., Andisheh, K., and Razavyan Amrei. A. 2009]. The Fig.6 shows the calculating result of B, and C for Sanandaj using Gumbel Function type III. According to the results B=2.15, and C=0.024.

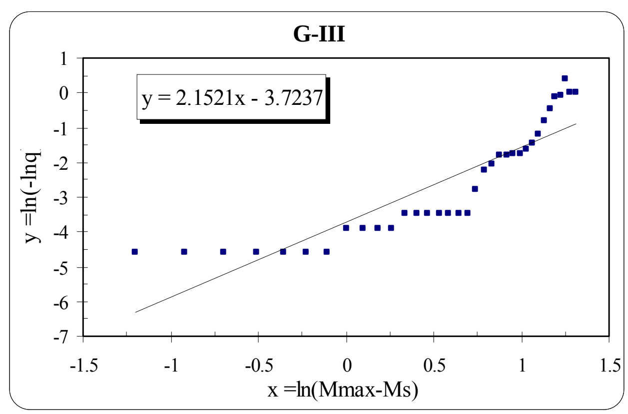

Fig.6. The calculating of seismicity parameters of Sanadaj using Gumbel Cumulative Distribution type III Function

Gumbel Cumulative Distribution Function type S. the Gumbel Function type S was shown in equation 4 and equation 7. The S type of cumulative function proposed by Howell is applicable in the case where a turning point exists in addition to the upper boundary limit in Type III. This turning point is defined as the magnitude of an earthquake less than the maximum magnitude

(Ms = 7.7) but more than earthquakes of reasonable magnitude (Ms = 3.0). In the easiest approach the number of earthquakes with a magnitude greater than this value is equal to the lower earthquakes in the mentioned domain. In this study the turning point for the earthquake magnitude is selected as 4 (M_a = 4). The Fig. 7 shows B= -3.51, C= 0.5537 using Gumbel Function type S.

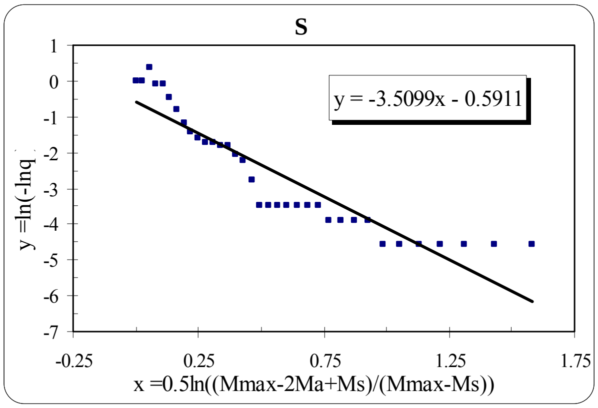

Fig.7. The calculating of seismicity parameters of Sanadaj using Gumbel Cumulative Distribution type S Function

RETURN PERIOD ANALYSIS OF EARTHQUAKES

After calculating the seismic hazard parameters, the return period of earthquakes in the studied region are calculated by all five applied methods. The Fig. 8 shows the relationship between return period and the magnitude that have been calculated by Gutenberg-Richter (G-R), third type of Gumbel Function (III), S type of Gumbel Function (S), first type of Gumbel Function (I), and Kijko method for sanandaj city. According to this analysis, an earthquake with the magnitude of 6 occurs in the studied region every 25, every 15, every 16, every 11, and every 100 years, according to Gutenberg-Richter, third type of Gumbel Function, S type of Gumbel Function, first type of Gumbel Function, and Kijko method respectively.

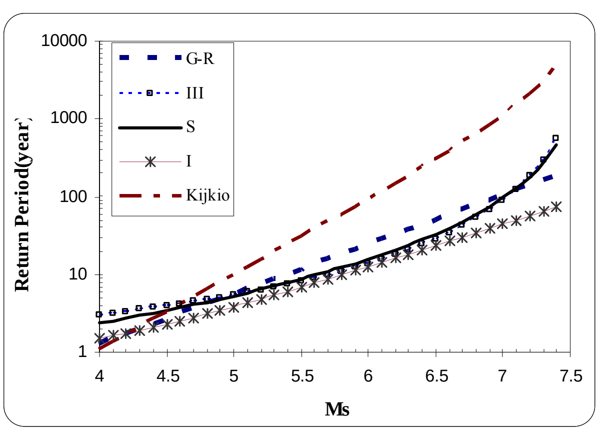

Fig.8. relationship between the return period and the magnitude by using Kijko method, Gutenberg-Richter method, Gumbel Cumulative Distribution Functions

CONCLUSION

In this paper a collection of main earthquake, has occurred from 1900 to 2006, in a radius 200 km around Sanandaj gathered, and location distribution and time distribution are plotted. The gathered earthquake records are considered to evaluating seismic parameters. The seismicity parameters calculated using five diverse method containing Kijko method, Gutenberg-Richter, first type Gumbel Function, third type Gumbel Function, and S type Gumbel Function. Using calculated seismicity parameters, relationships between return period and magnitude established by every one of five applied methods.

REFERENCES

Berberian, M., [1981], “Active faulting and tectonics of Iran”, In H. K. Gupta and F. M. Delany (editors), Zagros-Hindukish-Himalaya geodynamic evolution, Am. Geophys. Union, Geodynamic series, **3**, 33-69

Engdahl E. Robert, James A. Jackson, Stephen C. Myers, Eric A. Bergman and Keith Priestley [2006] "Relocation and assessment of seismicity in the Iran region" *Geophys. J. Int. 166, 237-277.*

Gardner, J.K., and Knopoff, L. [1974], “Is the sequence of earthquake in southern California, with aftershocks removed, Poissonian?” Bull. Seismol. Soc. Am., 64(5), 1363-1367.

Ghodrati Amiri, G., Andisheh, K., Razavyan Amrei, A. [2009] "Probabilistic Seismic Hazard Assessment of Sanandaj, Iran" Structural engineering and mechanics, 32 (4), 2009.

GUMBEL E. J. [1958], *"Statistics of Extremes."* Columbia University Press, New York.

Gutenberg, B., and C.F. Richter, [1954], "*Seismicity of the Earth and Associated Phenomena."* Princeton University Press, New Jersey.

Harvard Seismology education, [2007] “Centroid Moment Tensor (CMT) Catalogue”, online: http://www.Seismology.Harvard.edu/ CMT.search.html.

Hesami, K., H. Koyi, and C.J. Talbot, [2001], “The significance of strike-slip faulting in the basement of the zagros fold and thrust belt”, J. Petrol. Geol., 24(1), 5-28

Howell B. F. [1980] "Seismic risk in the central United States Earthquake notes, Eastern section." Bulletin of the Seismological Society of America, 51, No. 2, 13–19.

IRCOLD, Iranian Committee of Large Dams, [1994] *“Relationship between Ms and mb”*, Internal Report (In Persian).

Kijko, A., and M.A. Sellevoll, [1992], “Estimation of earthquake hazard parameters from incomplete data files. Part II. Incorporation of magnitude heterogeneity” Bull. Seismol. Soc. Am., 82(1), 120-134.

Kijko, A., [2000], “Statistical estimation of maximum regional earthquake magnitude Mmax”, Workshop of Seismicity Modeling in Seismic Hazard Mapping, Poljce, Slovenia, Geol. Survey, May 22-24, pp: 1-10.

Maggi, A., K. Priestley, and J. Jackson, [2002], “Focal Depths of Moderate and Large Size Earthquakes in Iran”. JSEE, summer and fall 2002, Vol. 4, No. 2&3, 1-10

Moinfar, A., Mahdavian, A. and Maleki, E. [1994],*"Historical and Instrumental Earthquake Data Collection of Iran"*, Iranian Cultural Fairs Institute, Iran

Talebian, M. and Jackson, J., [2004], "A reappraisal of earthquake focal mechanisms and active shortening in the Zagros mountains of Iran" Geophys. J. Int. 156, 506–526

Tchalenko, J. S., and Braud, J., [1974], “Seismicity and structure of the Zagros (Iran): The Main Recent Fault between 33 and 35 N.Philos. Trans. R. Soc. London, 227(1262), 1-25.