13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 1398

NEAR-FIELD EARTHQUAKE EFFECTS ON IRANIAN DESIGN BASIS ACCELERATION FOR TEHRAN

Gholamreza GHODRATI AMIRI[1], Gholamreza ABDOLLAHZADE DARZI[2] and Seiied Ali RAZAVIAN AMREI[3]

SUMMARY

The object of this paper is to investigate the near-field earthquake effects on the Iranian design basis acceleration in Tehran, the capital of Iran. One map has been prepared to indicate the earthquake hazard of Tehran and its vicinity in the form of iso-acceleration contour lines. It display the probabilistic estimate of Peak Ground Acceleration (PGA) over bedrock for the return period of 475 years. Tehran city, the capital of Iran, has its special features including highly dense population (more than 10 million people) and political and economical centralization, that make it prone to more severe earthquake damage in comparison to other regions. A collected catalogue, containing both historical and instrumental events and covering the period from the oldest destructive earthquakes happened (the 4th century BC) to 2003 is then used. For modeling seismic sources and establishing recurrence relationship the method proposed by Kijko [13] was employed considering uncertainty in magnitude and incomplete earthquake catalogue. The calculations were performed using the logic tree method and two weighted attenuation relationships; Cambell & Bozorgnia [1], 0.5, and Ambraseys & Douglas [2], 0.5. Seismic hazard assessment is then carried out for 13×15 grid points using SEISRISK III. Finally, one seismic hazard map of the studied area based on Peak Ground Acceleration (PGA) over bedrock for 10% probability of exceedence in life cycle of 50 years is presented. The result showed that the PGA in Tehran ranges from 0.34(g) to 0.52(g) for a return period of 475 years, whereas Iranian seismic code, both in the first and second revisions (1988, 1999), suggests the value of the design basis acceleration over bedrock A=0.35(g) for the entire Tehran region.

INTRODUCTION

Iran is one of the most seismic countries of the world. It is situated over the Himalayan-Alpied seismic belt and the Iranian plateau is one of the seismically active areas of the world and frequently suffers destructive and catastrophic earthquakes that cause heavy loss of human life and widespread damage. For example, Bam earthquake what caused over 40000 casualties, is one of the near-field case.

Tehran has been destroyed by catastrophic earthquakes, therefore the evaluation of the effects of earthquakes on seismic design of buildings of Tehran is indeed very necessary.

The most important factor in calculation of earthquake force based on the Iranian seismic code is having a reasonable value for the design basis acceleration over bedrock (A) that satisfies the scientific principles. The Iranian seismic code, both in the first and the second revisions [9, 10], suggests the value of A=0.35g for the entire Tehran region. Since in Tehran there are many active faults within the city, the evaluation of the near fault effects on the seismic design of buildings (and accordingly on the design basis acceleration over bedrock) is very important.

[1] Associate Professor, Iran University of Science and Technology, Tehran, Iran. Email: ghodrati@iust.ac.ir
[2] Ph.D. Candidate, Iran University of Science and Technology, Tehran, Iran. Email: abdollahzadeh@iust.ac.ir
[3] Ph.D. Student, Iran University of Science and Technology, Tehran, Iran. Email: razavian@iust.ac.ir

Considering the availability of newer and more complementing data and new scientific research, the need for performing hazard analysis for updating the corresponding results for an important and densely populated city like Tehran is now more than ever.
The most recent studies by Tavakoli and Ghafory-Ashtiany [17], Boland Payeh Co. [7] and Ghodrati-Amiri and Motamed and Rabet Es-Haghi [3] suggested the values of 0.45 g, 0.49g and ranging 0.27 g to 0.46 g respectively for a return period of 475 years in Tehran. In two first studies, the calculated value for the design basis acceleration for the return period of 475 years (the selected criterion for calculating the Iranian seismic code design basis acceleration) is greater than the suggested value by the seismic code and neither of these studies has employed the logic-tree. In fact they have not used different attenuation relationships and seismicity parameters. In latest study this value displayed as iso-acceleration contour that in some areas the value of the design basis acceleration is greater than and in other areas is smaller than what the Iranian seismic code suggested. Unlike before investigators, Ghotrati-Amiri & et al. with utilization the logic-tree employed different attenuation relationships and seismicity parameters.
Considering the importance of Tehran city and the fact that in inner and around this city have very important active faults and this area is affecting with near fault effects and the fact that in often last researches have been employed far-field attenuation relationships for this city, this paper introduces new research done in this concern using the latest and updated seismic data near-field attenuation relationships. This study provides bedrock design basis acceleration for calculation of earthquake equivalent static forces in the return period considered by the Iranian seismic code. The hazard zoning maps developed in this study represent statistical and average behavior of the region considered, mainly based on historical and instrumental data available on seismic events of the studied region.

Earthquake data base of Tehran

The seismotectonic conditions of Tehran region are under the influence of the condition of the Iranian tectonic plate in the Middle East. The most significant and primary faults in the vicinity of Tehran include: North Tehran and Niavaran thrust, Mosha, North Rey, South Rey, Kahrizak, Garmsar and Pishva faults. The locations of these faults can also be seen in Figure 1 within Tehran region.
In general, all earthquakes occurred in Tehran can be classified in 2 groups: (1) The historical earthquakes (pre-1900), and (2) The instrumentally recorded earthquakes (that occurred after1900).

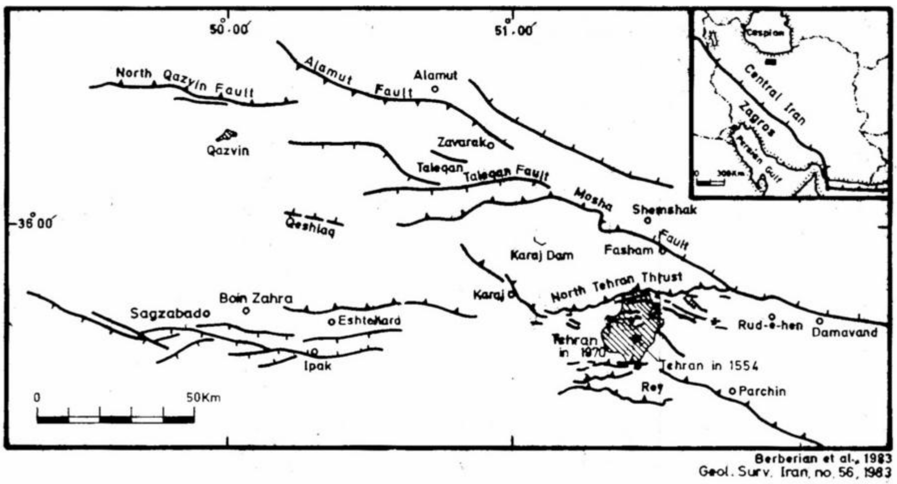


Fig. 1. Active faults of Tehran and its vicinity [6]

A review of Iran's historical earthquakes (pre-1900) is provided by Ambraseys and Melville [4]. To improve the quality and accuracy of these earthquake data the new Earthquake Catalogue of

Iran was compiled by Berberian in 1994. For the present century, the IIEES catalogue based on reports from international seismological institutes has been used.
With the inception of seismological stations, the location accuracy of the earthquakes has considerably improved since the mid 1960's. Thus, especially for Iran, it can be stated that a reliable earthquake database has existed only for the last few decades. Both of these catalogues have provided a base for the spatial correlation of the seismicity with the seismotectonic sources in Iran.
In this study because of the list of Iranian historical earthquakes, reported by Ambraseys and Melville [4], was more homogenous compared to other seismic lists, consequently this report is used for Iranian historical earthquakes in this paper.
For collect information about earthquakes in this study, a list of earthquakes and faults was gathered and selected in a preliminary manner for a radius of 60 km around Tehran. Reason of selection this radius for collection records is that in formation applied attenuation relationships in this paper, the maximum radius was supposed equal to 60 km. Application of probabilistic methods and use of other references were necessary due to the incompleteness of data regarding the depth and magnitude of earthquakes.
As shown in the catalogue (Appendix A) the column for focal depth is blank for many earthquakes due to incompleteness of the data. In Iran, due to lack of a precise seismic network, the precision of the recorded data (e.g. focal depth) has always been doubtful. Since the majority of earthquakes in Iran were shallow, in this paper, the focal depth of earthquakes was taken to be 10 km. Note that the variation of focal depth does not affect the results considerably.
In seismic hazard analysis usually one kind of magnitude is used, the surface- wave magnitude, M_S. In some special cases, body-wave magnitude, m_b, can also be used. Since some earthquakes reported with magnitude M_S and others with m_b, the equation presented by the Iranian Committee of Large Dams, IRCOLD [11], was employed (Equation 1) and the catalogue was completed for magnitude M_S using this equation .

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

Earthquake hazard Parameters of Tehran

The earthquake catalogue in a radius of 60 km has been gathered and processed, assuming the earthquakes follow a Poisson distribution. The seismic parameters, recurrence relationships, magnitude distributions and average occurrence rate were calculated using the Kijko method [13] for Tehran and its vicinity.

Determination of recurrence relationships

A recurrence model specifies the relative number of earthquakes of different magnitude levels. In most cases, earthquake recurrence is expressed by the Gutenburg-Richter b-line [8]:

$$\log N = a - b \times M \tag{2}$$

Where N is expected (or average) number of earthquakes of magnitude greater than or equal M, M is the earthquake magnitude, a and b are constants for a given source.
For determination of these parameters that is very important in seismic hazard analysis, the new method Kijko[13] was used in this paper.
In this study [13] the maximum likelihood method allows the combination of historical and instrumental data. Due to lack of sufficient seismic data and low precision of the available data, it is not possible to relate the occurrence of the earthquakes to their causative sources. As a result, it is not possible to calculate the seismic parameters for each source. Therefore, in this paper, the seismic parameters were obtained for Tehran city in a radius of 60 km.
Based on this method, three types of earthquakes were considered in this paper:
Historical earthquakes (before 1900) with magnitude uncertainty from 0.3 to 0.5. (Period #1)
Instrumentally recorded earthquakes from 1900 to 1963 (the time of world seismography network installation) with uncertainty of 0.2 and the threshold magnitude of 4.5. (Period #2)

Instrumentally recorded earthquakes from 1964 to 2003 with uncertainty of 0.1 and the threshold magnitude of 4. (Period #3)

In order to study the rate of seismicity and the effects of historical and instrumental data on seismic parameters in this region in the past, the Kijko [13] method was used in three cases (Table 1). In case 1, only the twentieth century earthquakes were used to evaluate seismic parameters. In case 2, only the historical earthquakes were used, and in case 3, combination of the historical earthquakes (with extreme value distribution function) and the twentieth century earthquakes (double extreme distribution function) were applied. The obtained values of β (b×ln10) and λ for each case are shown in Table 1.

In this paper, the primary emphasis was on the simultaneous application of all earthquakes (case 3) and all the calculations were based on the seismic parameters (β, λ) obtained from case 3 (Figure 2).

In Figure 2, the annual rate of occurrence, λ, for earthquakes with magnitude greater than 4 is presented.

Table 1. Seismicity parameters in different cases for Tehran

Catalogue	Parameter	Value	Data Contribution to the Parameters (%)		
			Case #1	Case #2	Case #3
20th Century Earthquakes Data	Beta	1.14		32.5	36.6
	Lambda (for Ms=4)	0.39		15.4	84.6
Historical Earthquakes Data	Beta	1.44	100		
	Lambda (for Ms=4)	0.56	100		
Historical and 20th Century Data	Beta	1.43	51.7	21.7	26.7
	Lambda (for Ms=4)	0.4	25.7	11.4	62.9

Determination of magnitude distribution

In determination of magnitude distribution the choice of magnitude for the maximum credible earthquake ($M_{\max}$) is very important. One of the method for determination of $M_{\max}$ is Geologic investigations. For example, correlations exist between surface fault length and maximum possible earthquake, that be used in this paper. The correlation between the maximum expected magnitude and fault length depends on the understanding of the seismotectonic and geotectonic behavior of the concerned area. Nowroozi [15] has offered equation (3) after the studying over 10 severe earthquakes in Iran and the observing the active faults' ruptures.

$$M_s = 1.259 + 1.244\log(L) \qquad (3)$$

In equation (3), M_S is the surface magnitude and L is the rupture length in meter. Note that the calculated $M_{\max}$ using this method is 7.8 ± 0.2 for Tehran.

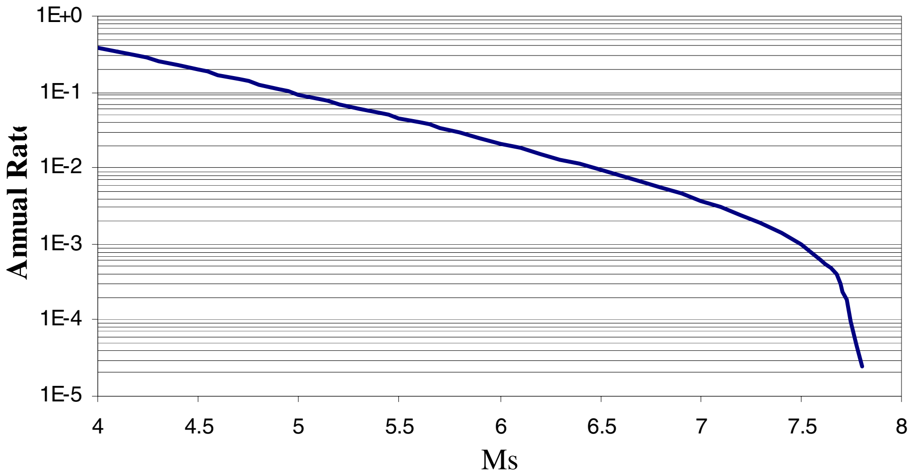


Fig. 2. Annual rates estimated by Kijko [13] method for Tehran and its vicinity

Attenuation relationships

For predicting future ground motions magnitude, distance and site conditions are the principal variables. A number of predictive relationships derived from regression analysis of strong motion data are available for peak horizontal ground acceleration, as well as, the analysis requires a seismic source model of the region and appropriate attenuation relationships.
In this research Cambell and Bozorgnia [1] and Ambraseys and Douglas [2] near source attenuation of peak horizontal acceleration from world-wide accelerograms records were employed using the logic-tree method. These relations were derived empirically from recorded accelerograms produced by earthquakes in different parts of the world,for maximum distance 60 km and 15 km respectively.

Approach and results of hazard analysis

For probabilistic seismic hazard assessment SEISRISK III [5], a computer program for seismic hazard estimation, was used to calculated peak ground accelerations. The calculated values for earthquakes hazard are displayed as iso-acceleration contours expected for return period 475 years. This program is based on the assumption that the site acceleration has a Poisson distribution with a mean annual rate. It is capable of modeling acceleration variability and permits the option of earthquake location uncertainty, as well as, smooth variation of seismicity across the boundaries of the zone.
The calculated values for earthquake hazard are displayed as iso-acceleration contour expected to be exceeded during typical economic lifetime of structures. In this study, the whole area of interest was subdivided into a grid of 13×15, total of 195 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 10% probability of being exceeded during life cycle of 50 years or for the ground motion return period of 475 years. In each site, seismic hazard curve is drawn, for example, in Figure 3, a typical curve can be seen. The result of the seismic hazard analysis is graphically shown in Figure 4.

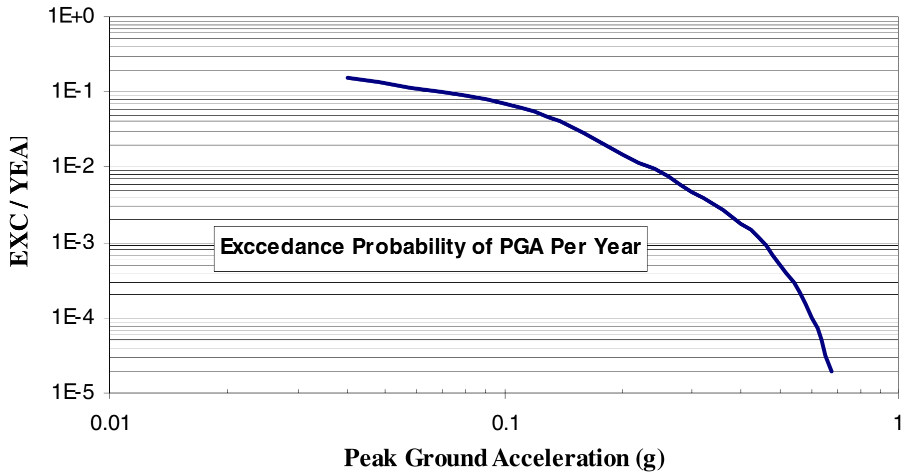


Fig.3. Mean seismic hazard curve for a site

Conclusions

This paper presents a probabilistic seismic hazard assessment of metropolitan Tehran and its vicinity. The significant results of this study can be summarized as:

(1) The contour levels of the acceleration hazard maps rang from 0.34g to 0.52g.

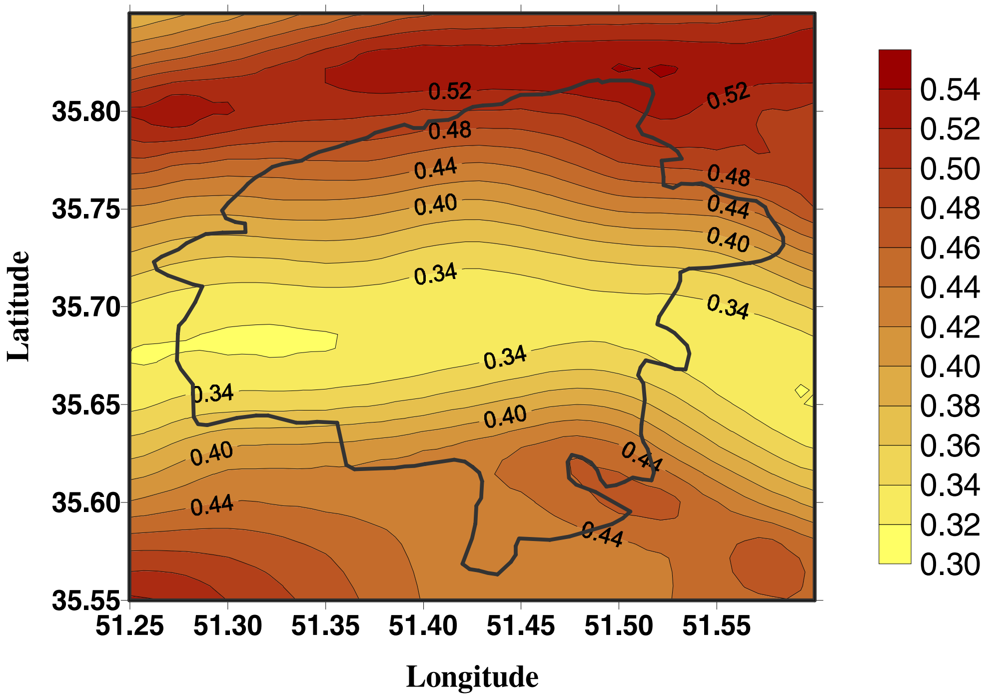
(2)The highest acceleration contours encompass the North and South Tehran in neighboring to faults.

(3) The smallest accelerations are expected in South-West and West Tehran.

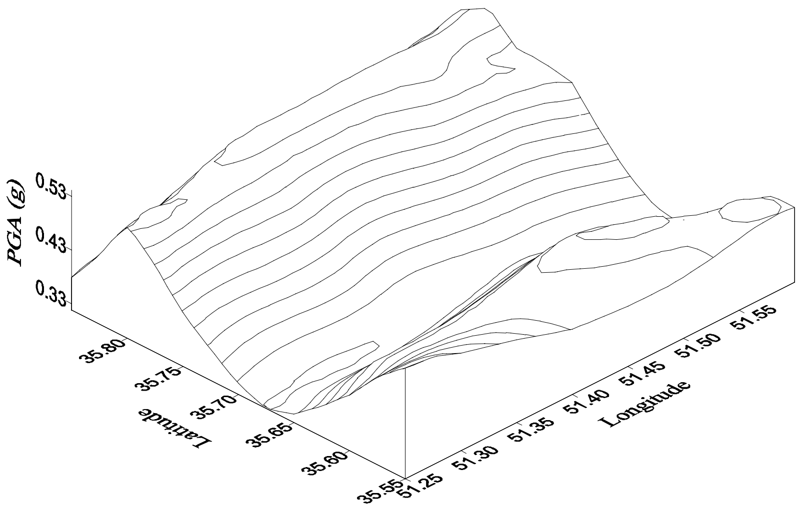
(4) Utilization of Two recent worldwide near field attenuation relationships using logic- tree method.

In this paper the seismic hazard analysis carried out was based on the assumption of an ideal bedrock case and therefore no influence of local soil condition is taken into consideration. The PGA in the interested area, ranges from 0.34g to 0.52g for a return period of 475 years. These values are justifiable compared to the results of previous works, in terms of the studied extended time span and using logic-tree method for including different near-field attenuation relationships and seismicity parameters.

Since only major known sources have been considered in the preparation of these maps, it is recommended that for important type of structures ,site specific studies which require deterministic hazard investigations, and identified local seismic sources on large scale maps be performed.



(a)



(b)

Fig. 4. Final seismic zoning map (PGA over bedrock) of Tehran and its vicinity using logic tree for 475 year return period (a) two-dimensional zoning map and the border of Tehran (thick line), (b) three-dimensional zoning map showing accelerations in g.

References

1. Cambell K. W, Bozorgnia Y. "Updated near- source ground-motion (attenuation) relationsfor the horizontal and vertical components of peak ground acceleration and acceleration response spectra." BSSA, 2003, Vol.93, No.1, 314-331.
2. Ambraseys N. N, Douglas J. "Near-field horizontal and vertical earthquake ground -motions"Soil Dynamics and Earthquake Engineering, 2003, 23, 1-18.
3. Ghodrati Amiri G, Motamed R, Rabet Es-Haghi H. "Seismic hazard assessment of meterpolitan Tehran, Iran." Journal of Earthquake Engineering, 2003, 7, 347-372.
4. Ambraseys N. N, Melville C. P. "A history of Persian earthquakes." Cambridge University Press, Cambridge, Britain, 1982.
5. Bender B, Perkins D. M. "SEISRISKIII, A computer program for seismic hazard estimation," U.S. Geological Survey, Bulletin 1772, 1987.
6. Berberian M, Ghoreishi, M, Ravesh, B. A, Ashjaei, A. M. "Seismotectonic and earthquake fault hazard investigations in the Tehran region," Geological Survey of Iran, Report No. 56 (in Persian), 1983.
7. Boland Payeh Co. "Seismic hazard analysis for Milad tower," Tehran, Iran (in Persian) , 1998.
8. Gutenberg, B. and Richter, C. F. "Seismicity of the Earth and Associated Phenomena." Princeton University Press, New Jersey, 1954.
9. "Iranian Code of Practice for Seismic Resistant Design of Buildings, Standard No.2800." First Revision, Building & Housing Research Center, Iran (in Persian), 1988.
10. "Iranian Code of Practice for Seismic Resistant Design of Buildings, Standard No.2800." Second Revision, Building & Housing Research Center, Iran (in Persian), 1999.
11. IRCOLD, Iranian Committee of Large Dams "Relationship between M_S and m_b," Internal Report (in Persian), 1994.
12. Kijko A, Sellevoll M. A. "Estimation of earthquake hazard parameters from incomplete data files. Part II, Incorporation of magnitude heterogeneity," *BSSA*, 1992, 82(1), 120-134.
13. Kijko A. "Statistical estimation of maximum regional earthquake magnitude m_{max}." Workshop of Seismicity Modeling in Seismic Hazard Mapping, Poljce, Slovenia, 2000, 22-24.
14. Kiremidjian A. S, Anagnos T. "Stochastic model for earthquake occurrence," Technical Report, The John A. Blume Earthquake Engineering Center, Stanford University, Stanford, California, 1983.
15. Nowroozi A. "Empirical relations between magnitude and fault parameters for earthquakes in Iran," BSSA, 1985, 75(5), 1327-1338.
16. Tavakoli B. "Major seismotectonic provinces of Iran," International Institute of Earthquake Engineering and Seismology, Internal Document. (in Persian), 1996.
17. Tavakoli B, Ghafory-Ashtiany M. "Seismic hazard assessment of Iran," Annali Di Geofisica 42, The Global Seismic Hazard Assessment Program (GSHAP) 1992-1999, 1999, 1013-1021.

Appendix A. Earthquake Catalogue

No.	Date			Time	Epicenter		FD	Magnitude			References
	Year	Month	Day	h:m:s	Lat.	Long.	(km)	Ms	mb	ML	
1	4 th. B.C				35.5	51.8		7.6			AMB
2	743				35.3	52.2		7.2			AMB
3	855				35.6	51.5		7.1			AMB
4	864	1			35.7	51		5.3			AMB
5	958	2	23		36	51.1		7.7			AMB
6	1177	5			35.7	50.7		7.2			AMB
7	1608	4	20	1200	36.4	50.5		7.6			AMB
8	1665				35.7	52.1		6.5			AMB
9	1830	4	6	1200	35.7	52.3		7.1			AMB
10	1901	5	20	122900	36.39	50.48		5.4			AMB
11	1930	10	2	153312	35.76	51.99	33	5.2			AMB
12	1940	9	25	193120	36.2	52.2		4.7	5		CCP (BAN)
13	1945	5	11	201728	35.18	52.4	33	4.4	4.7		BER. M
14	1954	9	2	224700	35.3	52		4.1	4.5		CCP (BAN)
15	1959	5	1	82357	36.5	52		5.1	5.3		CGS
16	1964	11	3	173606	35.86	50.39	18	5.1	5.3		NOW
17	1966	11	8	31414	36.1	50.8	38	4.7	5		USGS
18	1967	2	16	115532	35.74	51.88	16	4.0	4.4		CGS
19	1970	6	27	75758	35.2	50.7	14	4.6	4.9		USGS
20	1973	9	17	40602	36.5	51.19	40	4.4	4.7		ISC
21	1975	4	11	142646	35.65	50.35	59	4.4	4.7		ISC
22	1977	5	25	110147	34.91	52.06	39	5.1	5.3		ISC
23	1981	8	4	185360	36.45	51.27		4.4	4.7		ISC
24	1982	10	25	165452	35.13	52.38	44	4.2	4.5		ISC
25	1983	3	26	40719	35.96	52.23	33	5.2	5.4		NEIC
26	1988	1	14	112920	36.01	50.6	33	4.3	4.6		NEIC
27	1988	8	22	212335	35.28	52.35	10	4.7	5		NEIC
28	1993	3	8	191321.94	36.63	51.08	33	4.0	4.4		NEIC
29	1993	8	19	100428.8	35.09	52.09	18	4.3	4.6		NEIC
30	1994	11	21	185516.42	35.9	51.88	33	4.2	4.5		NEIC
31	1995	6	26	211255.88	36.56	51.2	33	4.2			NEIC
32	1997	11	5	224256.79	34.98	51.36	33	4.2	4.5		NEIC
33	1998	1	9	190613.84	36.47	52.17	33	4.5	4.8		NEIC
34	1998	12	3	131333.57	36.05	50.88	33	4.2	4.5		NEIC
35	2002	4	8	183058	36.42	52.03	46	4.5	4.8		BHRC
36	2002	5	21	104837	36.35	51.56	33	4.0	4.4		BHRC
37	2002	10	10	121343	35.89	52.33	33	4.4	4.7		BHRC

Table Notification
AMB: Ambraseys, N. N., Melville, C. P.
BER , M: Berberian, Geological and Mining Survey of Iran
BHRC: Building and Housing Research Center, IRAN
CCP (BAN): Atlas USSR Earthquake
CGS: U.S. Coast and Geodetic Survey, USA
ISC: International Seismological Center, UK
NOW: Nowroozi
NEIC: National Earthquake Information Center, USA
USGS: United States Geological Survey