An applicable modified probabilistic method for seismic hazard assessment in Northen Khorasan province, Iran

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Abstract: Iran plateau is a vast pressured region along mountain building belt of Alps-Himalayas. North Khorasan province where is studied in this research is located in Kope Dagh seismotectonic province. Kope Dagh seismotectonic province is a mountainous region which final phases of Alps have played a basic role in its present-day formation. This province is an active seismic region with mostly shallow earthquakes with less than 30 kilometers depth. Seismicity of the region indicates high activity in Northen Khorasan and Kope Dagh plate in the area of 56◦ to 59.30◦ E and 36◦ to 38◦ N. Regarding to the high seismicity and importance of Kope Dagh region because of the existence of Mozduran gas reservoir, which after refinement and desulphurization supplies fuel of Shirvan and Bojnourd cities, and due to economic and cultural importance, it is crucial to analyze seismic hazard in this region. It is important to note that however lots of studies have been done in north -east of Iran, but building codes modification needs more precisely seismic hazard analysis. Furthermore, previous studies have been applied free download softwares, which were provided before 2000, but the most important advantage of this study is applying professional industrial software, which has been written in 2009. This applied software can cover previous software weak points very well such as gridding potential sources, attention to the seismogenic zone and applying attenuation relationships directly.In the present study, modified probabilistic method has been applied instead of traditional one. For this purpose at first, a complete seismic catalogue of main earthquakes of the region provided. Then, map of potential sources prepare and compared to the previous studies. Finally, seismic parameters of the region have been determined for seismic hazard analysis.This study states the most PGA will be experienced in a northwest-central trend, which fits very well with Quchan-Robat and Esfarayen-Robatqarebil faults and matches with the expected trend based on tectonic evidences and previous statistical studies. In this research peak ground acceleration (PGA) will be experienced up to 0.07 gal during the expected earthquake with 63% probability of occurrence in 50 years in the area of Robatqarebil.

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Introduction

Among the areas prone to earthquake in Iran, Esfahan, Yazd, and the coastal plains of Khuzestan and Bushehr are the safest areas, while Azerbaijan (e.g., Tabriz, etc.) and Khorasan (e.g., Tabas, Bayaz Plain, etc.) are the most hazardous places. The studied area in the present research is located in active areas where are prone to distractive earthquakes (Ms > 6). The concerned zone in this study is located in longitude of 56◦ to 59◦ E and latitude of 36◦ to 38◦ N as a part of the Kope Dagh seismotectonic province, where several earthquakes have been happened. The required data in this study have been obtained from the seismic Network of Tehran University Geophysics Institute, as well as global seismic information web sites, such as ISC and USGS.

General Geology

Northen Khorasan Province, which is located in northeast of Iran, can be geologically divided into Kope Dagh and Binalood structural separate area parts.

a) **Kope Dagh structural Area:** The north and northwest parts of Northen Khorasan Province can be considered as a part of the northern Iran pressure zone in Kope Dagh. Geographically and orographically point of view, Kope Dagh is part of the eastern continuation of the Alborz Mountains. Its structural and geological features are different from those of the surrounding areas.

Kope Dagh is a mountainous area whose present form affected by the late Alpian phase. Normally, anticlines form the heights, whereas synclines form the between-mountains plains. Moreover, Mozduran carbonate components (upper Jurassic) and Tiregan lower Cretause are the typical units forming the appearance of this area. The Shirvan-Bojnord plain in this province is one of the low areas in Kope Dagh. The Kope Dagh Area has been formed as a sedimentary plate in the upper Triassic, where different types of continuous marine sediments, from Jurassic to Oligocene, are settled on each other with the same slope, as thick as 6000 meters. The sediment in the Kope Dagh sedimentary area in the Jurassic era is similar to that of the Alborz. Nevertheless, from Cretaceous, it has obtained its own specific features. Its stratigraphical hierarchy consists, in a chronological order, of the structures of Kashafrood, Chamanbid, Mozduran, Shuriche, Tirgan, Sarcheshme, Sangan, Etamir, Abderaz, Abtalkh, Neizar, Kalat, Pesteligh, Chehelkaman, and Khangiran. Moreover, it is as ancient as the Jurassic and Neogene. The zone is rich in gas resources and some non-metallic minerals.

b) **Binalood Structural Area:** This area is restricted between Tooran rigid plate and the mini-continent of central Iran. The south boundary is Mayamei fault or Shahrood fault, while its north-west boundary is Semnan fault. The zone is part of the Alborz, with individualistic geological features. Binalood geological unit is considered as the gradual zone between central Iran and the Alborz, since the sediment and Paleozoic features found in this zone are similar to those of the Alborz. The zone is rich at minerals, especially some metals, such as iron, and construction materials (Tchalenko, 1975).

In general, the main faults of the studied region, which earthquakes of this province occur due to them can be listed as:

1. **Main fault zone located in northeast (Kope Dagh):** it joins the north-west and Caspian Sea seismic belt; moreover, the Turkmen earthquakes are related to this zone.
2. **Bokharden-Quchan fault zone:** it causes greatest earthquakes in northeast of Iran.
3. **Baghan-Garmab fault:** extended in a NW-SE direction, it starts from near the Turkmen boundary and continues up to the cities Shirvan, Faruj, and Quchan. Its length is 50 to 55 km, and located in Kope Dagh.
4. **Esfarayen fault:** it is classified as being among seismic potential sources, having blind rupturing and causing earthquakes without outcrop.
5. **Robat-e-ghare Bil fault:** it is one of the Quaternary faults.
6. **Bojnord fault:** it causes several earthquakes with Ms more than 5. It is on the south of the Bojnourd city.
7. **Jajarm fault:** it is considered as one of the potential seismic sources with inverse focal mechanism (Berberian etal, 1982).

Statistical study of historical and instrumental events (1900-2011)

These events, which commonly are based on historical documents, contain time interval between 943 to1895. Figure1 depicts number of occurrence to time diagram in the notified period. Time intervals without any seismic activity are signified from the diagrams.

Iran's instrumental recording started at the end of 19th century with European seismograms. However, number of the stations well equipped by qualified recording instruments has been developed fast after 1963and again there is a quality improvement of data after 1973. Figures2 and 3 respectively show the number of events by time for time intervals of 1963 to 1974 and 1974 to 2011.

Seismic hazard assessment, probabilistic method

Probabilistic methods, which are applied to assess seismic hazard analysis, are provided by Cornel (1968). It has the following steps:

1- Determining seismic potential sources
2- Obtaining seismic parameters
3- Estimation of event effects in the desired site
4- Seismic hazard assessment for the desired site

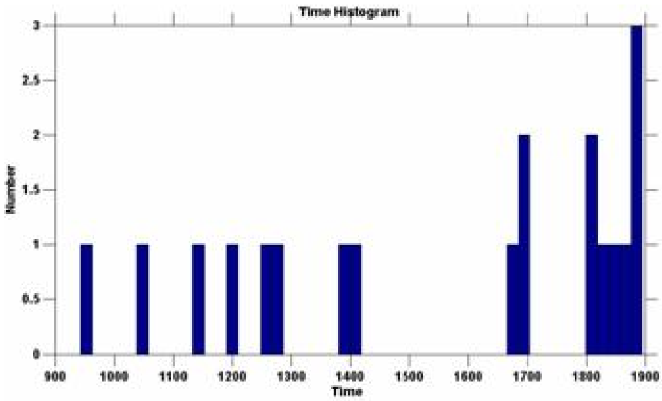

Figure1. Number of historical events by time

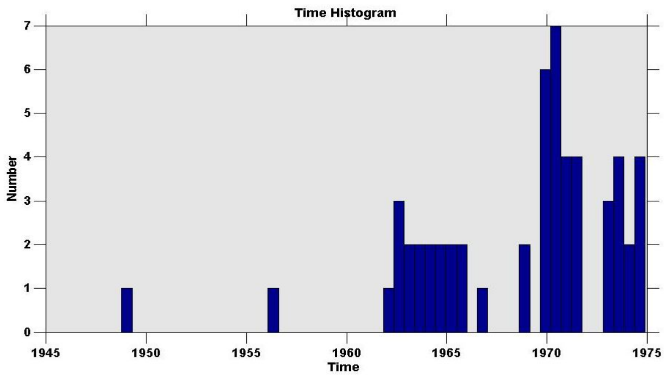

Figure2. Number of events by time (1963 to 1974)

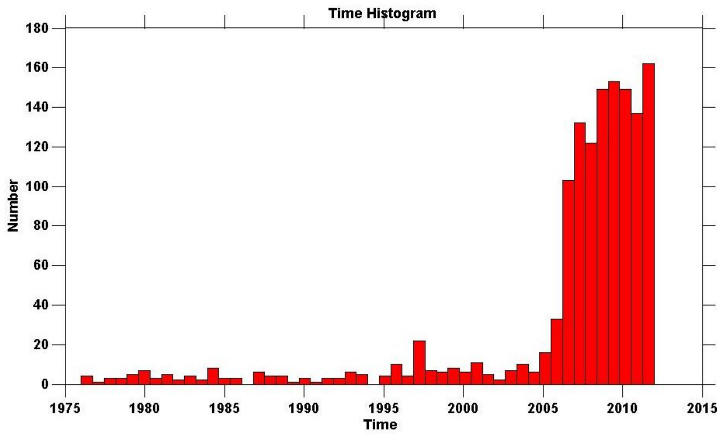

Figure3. Number of events by time (1974 to 2011)

Shi et al (1992) proposed a new method in hazard analysis, which can cover, lacks of the routine method, it is named modified probabilistic method with the following three essential steps which is showed in figure4.

1- Determining seismotectonic provinces and calculating seismic parameters in each province
2- Determining seismic potential sources , maximum magnitude (M max) for each potential source and calculation of special

distribution function in desired magnitude interval for each source

3- Gridding the studied area, hazard analysis for each node by using proper attenuation relationship and alternatively seismic zoning of the studied area.

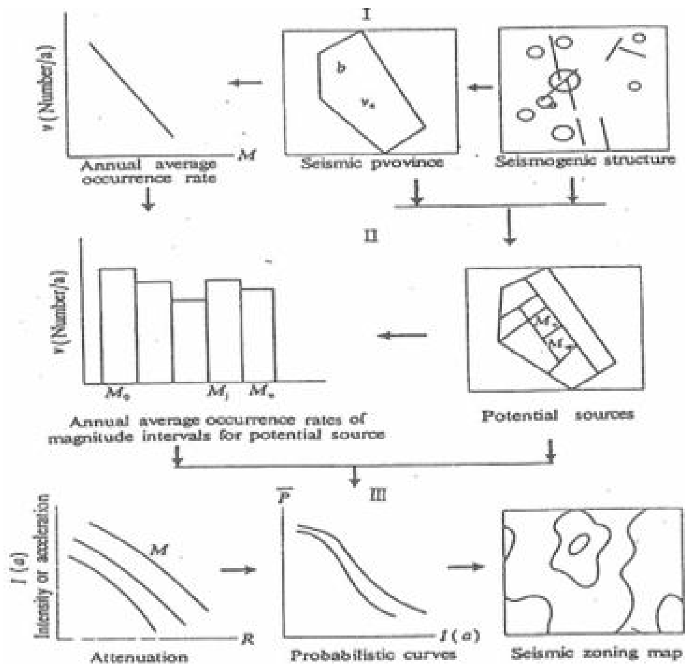

Figure4. Essential steps of modified probabilistic method (Shi et al, 1992)

Catalogue providing

The applied catalogue needs some process to be ready as an input for hazard assessment softwares, which needs the following steps.

- **Providing uniform catalogue:** To achieve a uniform catalogue a linear regression ($M_s = 1.14m_b - 0.883$) illustrates the relation between Ms and mb in the studied area. These results are given in figure5.

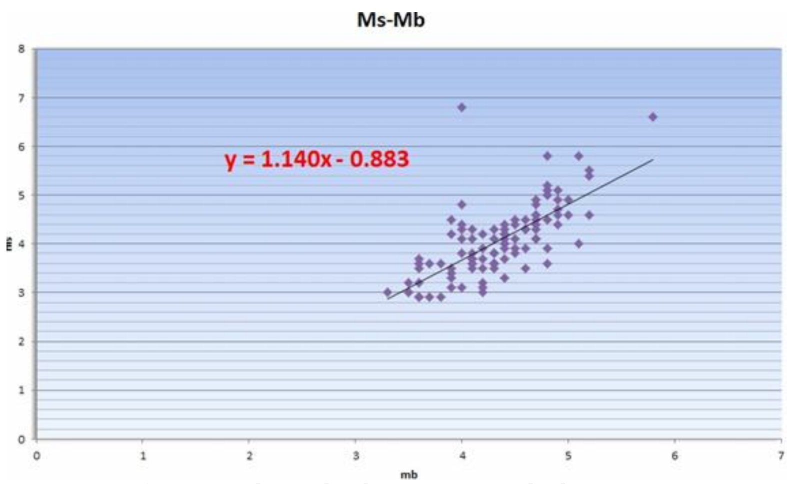

Figure5. Relationship between Ms and mb

- **Depended events omitting:** Probabilistic seismic hazard method assume earthquakes occurrence as Poisson function. Therefore, events happen along faults or area potential sources randomly in time and space. Events location, occurrence time and their magnitude are independent from other events. Normal distribution function of probability is described as following:

$$p(x,t)=\frac{(\lambda t)^x \exp(-\lambda t)}{x!}$$

Where; λ is seismic parameter and t is desired time interval. Therefore, foreshocks and aftershocks, which are taken into account as depended events, cannot match with Poisson function and should be removed from the catalogue.

A time window and a spatial window is needed to distinguish depended events. Regarding to crucial rule of the windows dimension, Gardner and Knopoff (1974) windows has been used in the present paper.

- **Completeness calculation:** The used catalogue is belonged to long time interval, which causes heterogeneity in time and space. Step method has been applied to evaluate catalogue completeness by $n = N/\Delta N$. Where; n is average rate of events and N is cumulative number of events. In this method, calculated variance equals to $\sigma_n^2 = n/\Delta t$ and standard deviation, σ_n, is parallel to line $1/\sqrt{\Delta t}$. In the present paper Mirzaii etal, (2000) completeness diagram is taken into account to apply Stepp's method. Table (1) shows complete beginning of catalogue completeness in different magnitude intervals for main seismotectonic provinces in Iran (Mirzaii, 1997)

Table (1). Completeness in different magnitude intervals for main seismotectonic provinces in Iran (Mirzaii, 1997)

6.0≤Ms	5.5≤Ms<6.0	5.0≤Ms<5.5	4.5≤Ms<5.0	4.0≤Ms<4.5	Seismotectonic province
1860	1900	1900	1945	1975	Alborz-Azarbayjan
1850	1904	1925	1963	1975	Kopeh-dagh
1860	1925	1944	1965	1975	Zagros
1900	1900	1955	1955	1975	Central Iran
1919	1919	1965	1965	1975	Makran

Potential seismic sources

In the present research potential sources determined by Mirzaii et al (2000) has been used but authors add some more sources regarding to the seismic activity of the area. Figure6 shows used potential sources in this study; all of them are area sources and diamonds indicate suggested potential sources by authors.

Seismic parameters

To describe seismic activity normally three parameters λ, β, M_{max} should be determined, λ presents seismic activity rate which means number of earthquakes with magnitude equal or greater than threshold magnitude (M_0) in time period (T), b or β $(\beta = b\ln(10))$ indicates ratio of small earthquakes to large ones. Table (2) contains calculated seismic parameters for each potential source.

Seismic hazard analysis and seismic zoning

Figure7 illustrates seismic zoning map of the studied area for 63% occurrence probability for return period of 50 years. It contains PGA contours of the area. This area will experience maximum PGA of 0.07 g and minimum PGA will be 0.012 in north east of the area.

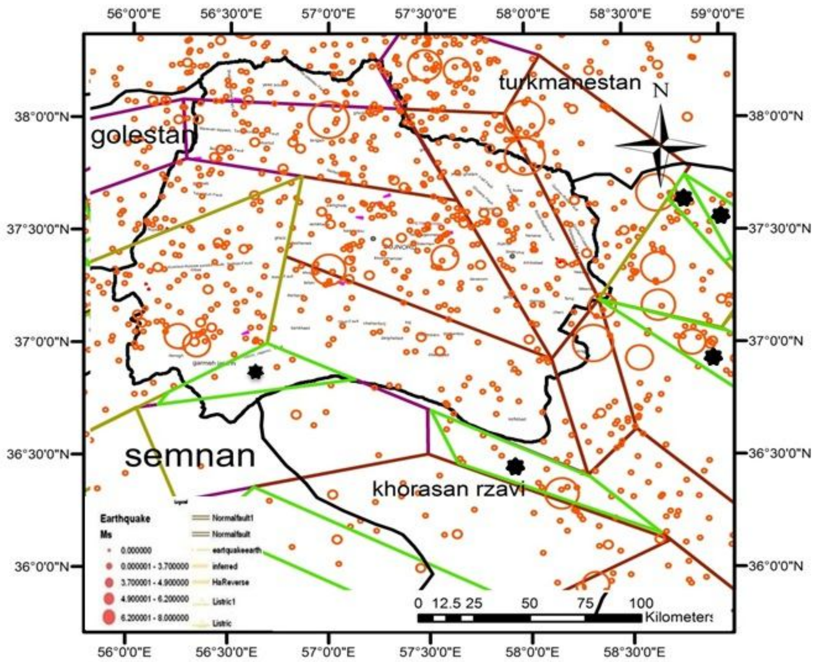

Figure6. seismic potential sources (Mirzaii etal, 2000)

Table (2). Seismic parameters in each potential source

seismic sources	number of earthquakes	LAMBDA	BETA	Mmax
1	37	0.22	2.62	4.5
2	72	0.46	2.62	7.6
3	79	0.19	2.62	6.6
4	7	0.04	2.62	3.4
5	134	0.80	2.62	5.8
6	66	0.43	2.62	4.8
7	104	0.64	2.62	7
8	76	0.39	2.62	4.9
9	57	0.35	2.62	7.2
10	10	0.17	2.62	4
11	5	0.15	2.62	2.6
12	8	0.15	2.62	4.4
13	54	0.33	2.62	4.3
14	15	0.10	2.62	7.1
15	33	0.17	2.62	6.9
16	5	0.06	2.62	2.7
17	29	0.22	2.62	5
18	42	0.31	2.62	7.6
19	35	0.20	2.62	4.6
20	1	0.06	2.62	4.4
21	1	0.04	2.62	2.3
22	19	0.11	2.62	5.3
23	16	0.15	2.62	5.2
24	4	0.06	2.62	4.5
25	1	0.06	2.62	4.5
26	12	0.09	2.62	4.5
27	0	0.09	2.62	0

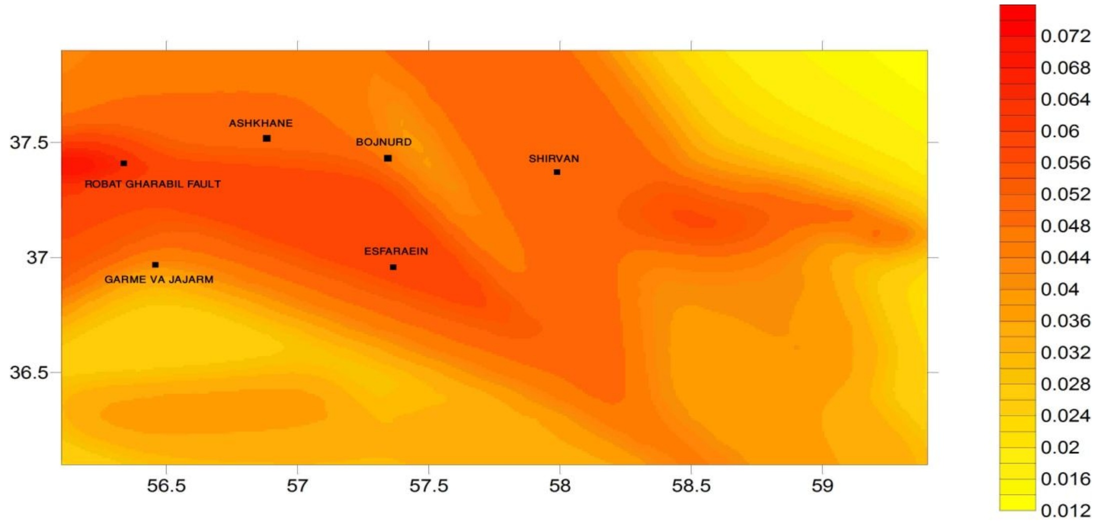

Figure7. Seismic zoning map for 63% occurrence probability in return period of 50 years

Conclusion and discussion

In the present study although different attenuation relations were taken into account the most precisely mapping obtained from Ambersays (1996) attenuation relations.

Seismic zoning map indicates that the greatest PGA will be experienced in northwest- central trend up to 0.07g, which has strong correlation with Robat Gharabi and Esfarayen faults therefore Esfarayen city, and Robatgharabil region are the most hazardous places in the studied area. Minimum PGA is estimated for south of Jajarm city up to 0.012g.

In this study area sources play role as seismic sources but seismogenic zone studied can guide us to plan volume sources, which can obtain more accurate results. Site effect should be considered in such studies to achieve risk assessment in the area.

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