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Probabilistic Seismic Hazard Analysis Using the New Correlation Relationships for Magnitude Scales

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Abstract

Amol is one of the oldest cities located in north of Iran, Mazandaran province, and its history dates back to the pre-Islamic period. Amol is a city with an area about 3000 square kilometers, a population exceeding 370,000, and includes the old and famous neighborhoods that have a religious, commercial, and service with a long history background. Considering the importance of buildings constructed in this city and the need for their preservation and restoration on one hand, and the occurrence of many severe earthquakes in the past centuries, as well as the recent earthquakes of the last century, on the other hand, encourage us to study the seismicity of this city. Therefore, in this paper, by considering the historical and instrumental earthquakes recorded within a radius of 150 km around this city and the seismic mechanism of the faults located in this region, probabilistic seismic hazard analysis of the area is studied. Then, using the probabilistic relations of the seismic hazard analysis of the Kijko 2000 computer program, the seismicity parameters and the return periods of the earthquake magnitudes are obtained for the area, and at the end, the horizontal peak ground acceleration is zoned for this city.

Keywords: Amol Area; Historical Background; Seismicity Parameters; Earthquake Return Period; Peak Ground Acceleration.

1. Introduction

Probabilistic seismic hazard analysis (PSHA) method was first introduced by Cornell [1] in 1968. This method was based on the identification and evaluation of seismic sources around the site under study, and defining a distribution to estimate any desired parameter of strong ground motion for the site during a certain period of time. The seismic sources can be selected within a radius of 100 to 300 km around the site based on the importance of existing structures.

After the identification and modeling of the seismic sources, the maximum capable earthquake for each source must be estimated. For this purpose, since faults are the most important seismic sources, fortunately, a variety of empirical relationships between the earthquake magnitude and rupture characteristics of the faults have been given by different researchers, among which the most comprehensive work was conducted by Wells and Coppersmith in 1994 [2]. They introduced several empirical relationships between moment magnitude and fault rupture characteristics including rupture length, rupture area, and even maximum displacement for different types of faults by collecting data from all over the world. However, some other researches have also been performed for this purpose such as Wyss [3] and Bonila [4]. Moreover, in Iran also some researches have been carried out in this field. Nowroozi in 1985 [5] by studying 14 strong earthquakes occurred in Iran; and Zare in 1995 [6], by investigating 22 earthquakes occurred on more than 20 seismic faults in Iran, have presented some empirical relationships for this purpose.

Many seismic studies have been carried out around the world till now, in which most of them was based on the well-

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known primary Gutenberg-Richter relationship [7]. This relationship includes two basic parameters known as the “seismicity parameters”. But this relationship alone is not sufficient for seismic hazard assessment, because it does not consider any limits for earthquake magnitude and may take large numbers, while the earthquake magnitude varies between some limited ranges. Another major problem in all of these studies was that there are two different seismic patterns: Earthquakes reported in historical writings that have occurred over a period of several hundred years, and the complete instrumental data that have occurred in a relatively short period of time.

In fact, the uncertainties exist in the earthquake magnitude, and incompleteness of data used for analyses were the most important issues existed in the estimation of seismicity parameters from the above assumptions. But Kijko and Sellevoll proposed a different solution which is able to combine the incomplete data of the first group and the complete data of the second group [8]. They proposed that to estimate the seismicity parameters by assuming the extreme values distribution for incomplete data of first group, and two bounded distribution of Gutenberg-Richter for the complete data of second group; and then by using maximum likelihood estimation and considering two uncertainty models, these parameters can be obtained by a combination of both [8,9]. They have written a computer program in FORTRAN in 2000 A.D., introducing an accurate and convenient method to assess the seismicity parameters for any given area. The first step to adapt the earthquakes catalog with the assumptions of Kijko and Sellevoll method is to remove aftershocks and foreshocks from the catalog. Because some of researchers such as Knopoff have proved that aftershocks and foreshocks are depend to the original earthquake [10], while the basic assumption of kijko method and Gutenberg–Richter relationship is independence of data.

By having the main shocks catalog and obtaining the seismicity parameters, some attenuation relationships are needed to link the strong ground motion parameters to the earthquake source parameters. Trifunac and Ambraseys can be mentioned as the leading providers of attenuation relationships. Trifunac and his coworkers [11] in 70th decade A.D., by investigating the data of state of California, USA, published one of the most complete attenuation relationships untill that time. After the 80s, many researchers from around the world including Abrahamson [12], Sarma [13], Ambraseys [14, 15] and Campbell and Bozorgnia [16], using earthquakes data from around the world proposed a variety of attenuation relationships.

Ramazi and Schenk [17] proposed the first research formed on the basis of the Iranian strong ground motion data catalog in 1994. But, undoubtedly, the attenuation relationship presented by Zare in 1999 [18] can be regarded as one of the most comprehensive relationships provided by researchers in Iran. He released his relationship based on 468 three-component strong motion data from five large earthquakes occurred in Iran, namely: Manjil, (1990), Sirach (1981), Golbaf (1980), Tabas (1979) and Naghan (1978). Also, Ghodrati et al in 2007 and 2009 [19,20], Sharma et al in 2009 [21], Yazdani and Kowsari in 2013 [22], and Campbell and Bozorgnia in 2014 [23] suggested new attenuation relations for PGA and PGV based on update data from earthquakes in Iran, with different coefficients for different parts of Iran.

During the last three decades, many studies have been performed to evaluate seismic hazard, all are based on the primary Gutenberg-Richter relationship. Nowroozi is one of the pioneers in the field of seismic hazard study in Iran. In 1986, Nowroozi and Ahmadi [24], after re-locating 600 earthquakes occurred in Iran from 1920 to 1972, performed a seismic hazard analysis in Iran based on the primary Gutenberg-Richter relationship. They divided entire Iran to 23 seismotectonic states with specified parameters. After them, Tavakoli et al in 1999 [25], using the probabilistic method of Kijko, and dividing entire Iran to 20 seismic states performed another seismic hazard analysis based on the data from 1927 to 1995, resulting to seismicity parameters for each state. Ghodrati also conducted a seismic hazard analysis for different regions of Iran using the Kijko method [26-28].

But it should be noted that in none of the above mentioned studies for Iran, nothing is illustrated about the selection of magnitude threshold level of earthquakes and the resulting error in seismic hazard analysis. Another important issue in this subject relates to the relationships needed to inter-convert different earthquake-magnitude scales. Different relationships have been proposed for this purpose in the world, but the vast majority of them are based on earthquakes occurred around the world. Although some of these relationships such as that one given by Iranian Committee of Large Dams (IRCOLD) [29] and the relationship given by Mirzaei [30] have been proposed based on earthquakes occurred in Iran, none of them covers different magnitude scales. Also, Alizadeh et al [31] by considering the multitude of Iran total data and of course their remarkable accuracy, reliable relationships exploit for assessment of seismicity in each favorite part of this area and even its adjacent lands.In the present paper, probabilistic seismic hazard analysis is conducted for Amol Area.

Amol city is located in geographic range of 52.35º north longitude and 36.47º east latitude; in the Mazandaran province in north of Iran and along the Haraz river with a height of 76 meters above the sea level, with an area about 3000 square kilometers, and with a distance of 70 km at the west of Sari city center, 18 km south of Caspian sea, 6 km north of the Alborz mountain range, and 180 km northeast of Tehran. Due to the remarkable region's population, and existing important historical structures, seismicity studies of the area could be crucial. Considering the severe historical and instrumental earthquakes in the region, the probability of the earthquake occurrence with high intensity in the region is expected.

The main objective of this paper is to evaluate the peak ground acceleration coefficient (defined in Iranian standard No. 2800 [32] to calculate the base shear force due to earthquake) using probabilistic seismic hazard analysis, PSHA, for Amol area. For this purpose, at the first, the latest status of the major faults in the area; the reported historical earthquakes; and the registered instrumental earthquakes up to the 2017 A.D. within a radius of 150 km from the center of the city have been collected and studied. Then, after removal of aftershocks and foreshocks by using time and place windows method, seismicity parameters and the earthquake return periods of the region for seismic hazard analysis are obtained by calculating the frequency of earthquakes using the probabilistic relationships of Kijko 2000 computer program. Finally, the zoning map of the horizontal peak ground acceleration coefficient for Amol city and its suburbs have been obtained by using Seisrisk III hazard analysis software.

2. Seismicity and Seismotectonics of Region

2.1. Iran Area

The land of Iran is located in geographic range of 25-40° north latitude and 44-64° east longitude with an area of about 1,648,000 square kilometers and a population of over 80 million people, limited to the Caspian sea and its sidelines from the north, Persian Gulf and Oman sea from the south, Pakistan and Afghanistan countries from the east, and Iraq and Turkey countries from the west. Due to its placement in the middle part of the Alp-Himalaya orogenic belt, the country of Iran has become one of the most seismically active zones of the world. Tectonic models based on analysis of the global expansion of the oceanic beds, faults system and scrolling vector of faults, show that Arabic Shield with the north direction and a song between 30 to 40 mm in year, are moving toward Eurasian plate [33] (Figure 1). This convergence caused shortening of Persia crust, creating Zagros and Alborz mountains, and occurrence of many earthquakes in the Iranian plateau.

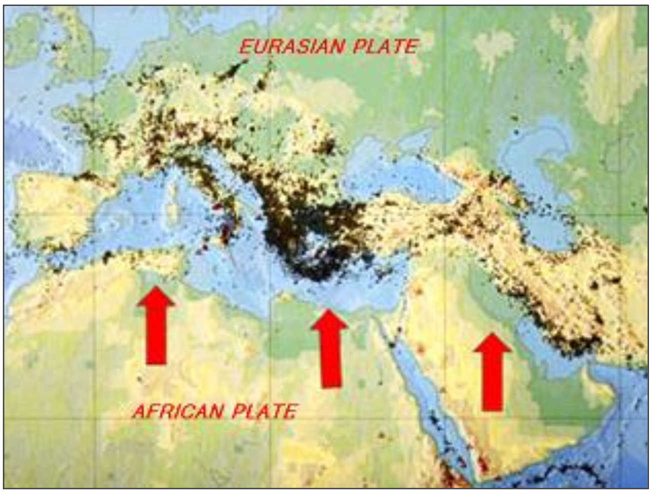

Figure 1. Tectonic of Middle East

Iran has experienced many large and devastating historical earthquakes, which has been registered by many historians around the world because of its long and old precedence. The distribution of historical earthquakes in the Figure 2 indicates the high seismicity of this region. Dark areas on the map show the destroyed areas influenced by the earthquakes occurred throughout the history.

By the advent of the seismic devices in the world from 1900 onwards and the installation of the world standard seismic network from 1964, more earthquakes have been recorded in this region of the world. Table 1 shows some destructive earthquakes happened in Iran throughout the history.

In view of seismotectonics, Iran area can generally be divided into four states: strip folded-driven Zagros, Makran range in southeast Iran, the Central Iranian plateau, and Alborz Mountains. During the studies performed so far, about one hundred major faults with the specified mechanism have been identified in Iran that almost over than 60% of them are reverse type, and the rest are of normal slip type (Figure 3). Table 2 shows some of the major faults in this region with their known specifications. It can be seen from the table, that one of the longest and most active fault, which can be very important in view of seismicity for this area, is the Alborz (Khazar) fault located in the north of Iran and the region studied in this paper.

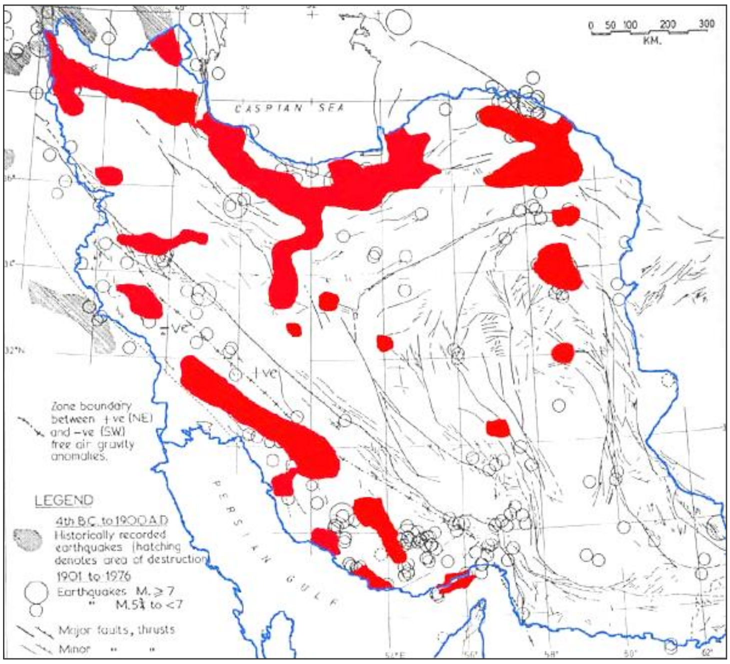

Figure 2. Spatial epicenter distributions of Iran's historical earthquakes along with the indication of damaged areas

Table 1. The strong earthquakes occurred in the area of Iran

No.	Year	Casualties & losses registered	Location	Magnitude (M_S)
1	815	A lot of dead &damage	Zahedan	7.6
2	943	A lot of dead &damage	Bojnourd	7.6
3	1008	A lot of dead &damage	Bushehr	7.5
4	1493	A lot of dead &damage	Birjand	7.7
5	1608	A lot of dead &damage	Ghazvin	7.6
6	1721	A lot of dead &damage	Tabriz	7.7
7	1830	A lot of dead &damage	Tehran	7.1
8	1890	A lot of dead &damage	Gorgan	7.2
9	1909	8000 dead, 64 villages destroyed	Silakhor	7.4
10	1930	2514 dead, 60 villages destroyed	Salmas	7.4
11	1962	10000 dead, destructive damage	Buyin Zahra	7.2
12	1968	10500 dead, 61 villages destroyed	Dasht-e-Bayaz	7.4
13	1972	4000 dead, a lot of damage	Qir	6.9
14	1978	19600 dead, 16 villages destroyed	Tabas	7.7
15	1990	35000 dead, destructive damage	Rudbar-Manjil	7.4
16	2003	41000 dead, destructive damage	Bam	6.5
17	2004	612 dead, 10 villages destroyed	Zarand	6.4
18	2017	620 dead, destructive damage	Kermanshah	7.3

Table 2. Newest specification of main active faults in Iran

No.	Fault	Type	Length (km)	Background seismicity
1	Alborz (Khazar)	Thrust-Inverse	523	7
2	North alborz	Thrust-Inverse	360	4
3	Astara (Talesh)	Thrust-Inverse	400	2
4	Anar	Right-lateral	100	-
5	Copeh-dagh	Thrust-Inverse	140	1
6	Kazeroon	Right-lateral	45	3
7	Niband	Right-lateral	400	-
8	North tabriz	Right-lateral	150	2
9	Mosha	Thrust-Inverse	200	9
10	Koohbanan	Thrust-Inverse	300	1
11	North tehran	Thrust-Inverse	85	1
12	Garmsar	Thrust-Inverse	100	5
13	Nosrat abad	Lateral	197	1
14	Roodbar	Right-lateral	93	2
15	Dasht bayaz	Thrust-Inverse	135	1
16	Tabas	Thrust-Inverse	160	1

Figure 3. Active fault distributions in Iran

2.2. Amol Zone

As noted earlier, in the point of Seismotectonics view, Iran area is divided into four states which Amol zone is located in the last state, Alborz Mountains. In terms of seismicity, existing of multiple faults in the Alborz region has led to the identification of one of the most Seismotectonics regions of Iran with high seismic risk. The Mazandaran province which includes the Amol city also, is located in this most Seismotectonics region.

More than 20 major and minor faults have been identified in surrounding Mazandaran zone [34-37]. By considering various factors including the proximity to the Amol city and faults seismicity background, among the above 20 faults, 12 faults have been selected for seismicity studies of this area. Figure 4 shows the last position of these seismicity sources in surrounding area of Amol.

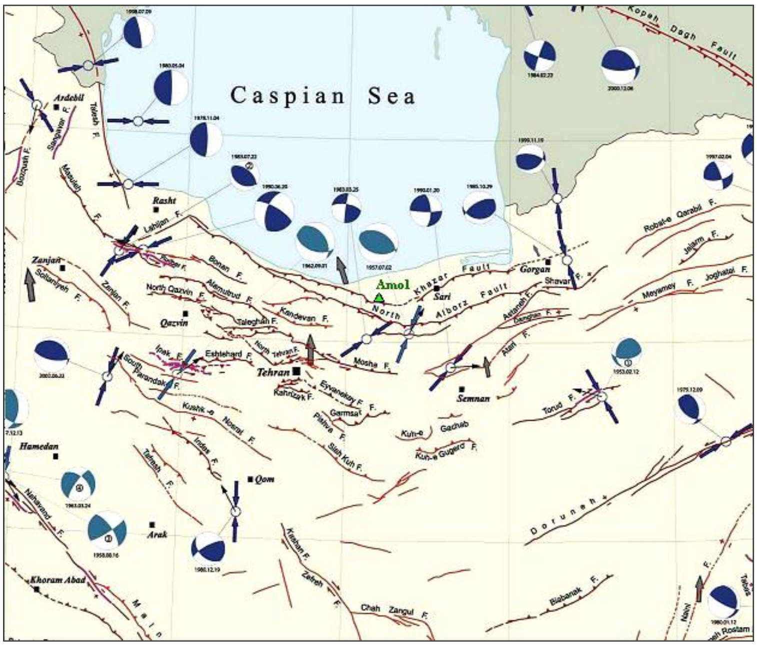

Figure 4. The position of the faults in Amol range

More descriptions of active faults in this area are provided in Table 3. It should be mentioned that there are many different relationships between the maximum capable earthquake magnitude and the length of causing fault in terms of different magnitude scales. In this paper, the Nowroozi's relationship has been used [5] for this purpose in terms of surface-wave magnitude scale (M_S) and the effective length of the fault as follows:

$$M_s = 1.259 + 1.24\log(L) \tag{1}$$

Where L is the effective length of the fault rupture that is expressed as a percentage of the overall length of fault; and log is the logarithm in the basis of 10.

Table 3. Profile of main active faults within a radius of 150 Km around the Amol zone

No.	Fault Name	Mechanism of Fault	Overall Length of Fault , Km	Rupture Length of Fault , Km	Seismicity Background	Maximum Earthquake Magnitude (M_S)
1	Alborz (Caspian)	Reverse Thrust	523	160	7	7.7
2	North Alborz	Reverse Thrust	360	110	4	7.5
3	Mosha	Reverse Thrust	400	130	11	7.6
4	Taleghan	Reverse Thrust	64	32	2	6.8
5	North Tehran	Left Lateral	108	54	5	7.1
6	Ivanaki (Parchin)	Reverse Thrust	80	40	5	7
7	Astaneh	Left Lateral	75	37	1	6.9
8	Koior	Reverse Thrust	30	15	1	6.4
9	Attari	-	70	35	-	6.9
10	Javaherdasht	Reverse Thrust	74	37	-	7
11	Kandovan	Reverse Thrust	50	25	-	6.7
12	Firozkoh	Reverse Thrust	35	17.5	1	6.5

Seismicity history of the Alborz tectonic region shows that occurrence of many devastating historical and instrumental earthquakes have destroyed many towns and villages in this area of the country. In Table 4, some of these destructive earthquakes are shown.

Table 4. Historical and instrumental strong earthquakes occurred within a radius of 150 Km around the Amol zone

No.	Year of Earthquake Occurrence	Place of Earthquake Occurrence	Magnitude (M_S)
1	1301	Sari	7.6
2	1485	Ramsar	7.2
3	1608	Taleghan	7.6
5	1808	Shahsavar	5.9
6	1809	Amol	5.6
7	1825	Haraz	7.6
8	1935	Talarrod	5.8
9	1935	Kosot	6.3
10	1957	Chelav	6.8
11	1971	Babolkenar	5.2
12	1990	Gadok	5.9
13	2004	Kojor	6.5

3. Earthquakes Catalog

To obtain the seismicity parameters and perform the probabilistic seismic hazard analysis, PSHA, 26 historical and more than 300 instrumental earthquake sets with magnitudes greater than 4 on Surface-wave magnitude scale (M_S) up to the 2017 A.D. are collected in the surrounding area of Amol zone [37-40] and used in the present study. As well, by noting to the facts that all the instrumental earthquakes recorded in Iran since 2004, on one hand, and the small magnitude earthquakes have very low risks in point of structural engineering view, on the other hand, magnitudes larger than 3.5 on Surface-wave scales (M_S) from 2004 onwards are also considered in the analysis. Figure 5 shows the distribution of instrumental earthquakes of the catalog till 2017 A.D. with magnitude greater than 3.5 on Surface-wave scale (M_S).

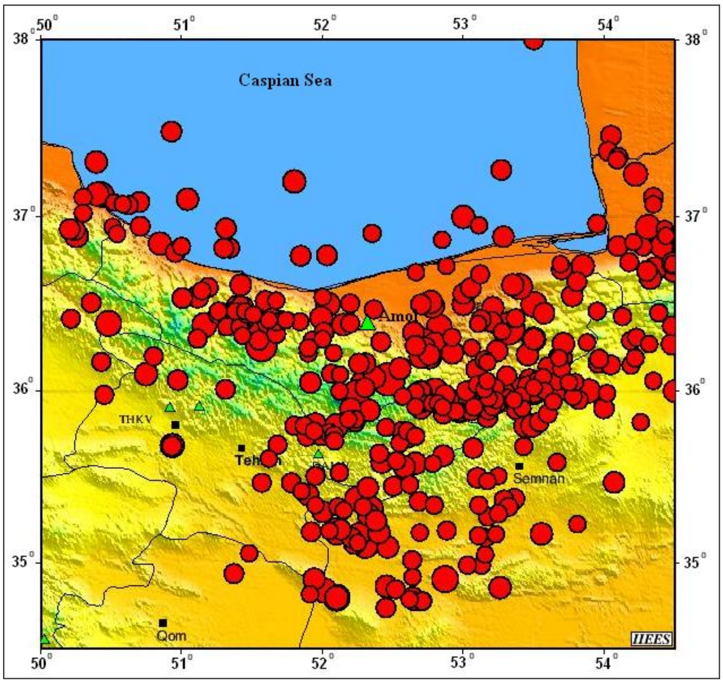

Figure 5. Distribution of instrumental earthquakes in Amol area with surface waves magnitude scale (M_S) greater than 3.5

For assessment of seismicity activity in any region, all the earthquake magnitudes that are used should be given in a single scale. For this purpose, we need relationships to inter-convert different magnitude scales. Various relationships are proposed for this purpose around the world, but many of these relationships are evaluated based on the earthquakes occurred around the world, and it is possible that these relationships do not provide appropriate results for a specific area, such as Iran.

In this way, using these relationships, all the earthquake magnitude scales were greatly converted to surface waves magnitude scale (M_S) and used for seismic hazard analysis. However, some relationships are provided based on earthquakes occurred in Iran, such as the relationships presented by the Iranian National Committee of large dams (IRCOLD) [29], and Mirzaei [30], but these relationships either do not cover all magnitude scales or the data used in these relationships has not high plurality. Also, many seismic hazard studies are performed by different researchers including Tavakoli [25], Ghodrati et al [26-28], Yazdani And Kowsari [41], Asadi et al [42], and Zare [43] for different regions of Iran. But in all of these studies, no new relationship is provided for Iran, and only the ancient relationships, which maybe are given for other countries, are being used. Therefore, in the present paper, it has been tried to use the new relationships to inter-convert the different earthquake magnitude scales for Iran, given by Alizadeh et al [31] by using the catalog of total earthquakes occurred in Iran. Considering the multitude of data used in this catalog and of course their remarkable accuracy, these new relationships can be exploited for assessment of seismicity in each favorite part of this area and even its adjacent lands.

In this way, using these relationships, all were greatly converted to surface waves magnitude scale (M_S) and evaluated for seismic hazard analysis.

4. Seismicity Parameters of Amol Zone

So far various statistical methods are provided to estimate the seismicity parameters all of which are based on the initial Gutenberg-Richter relationship [7]. Basic method of Gutenberg-Richter establishes a linear relationship between frequency and magnitude of earthquakes as below:

$$log\lambda(m) = a - b.M \tag{2}$$

Where "λ (m)" is the rate of mean occurrence of earthquakes with magnitude equal or greater than "M" at a specified time period; "b" is seismicity coefficient; and "a" is number of events greater than "M_{min}".

By considering that errors in seismic data in the region under study are not the same at different time periods, and on the other hand, due to inadequate and low accuracy of existing data, therefore use of the primary Gutenberg-Richter method and curve fitting procedure for obtaining the values of parameters, do not provide accurate results. Since these parameters have very high importance in estimating the time return period of the earthquakes, therefore in this study it is attempted to use a more accurate method that is compatible with the seismic data in Iran. The methods which have been introduced after the primary Gutenberg-Richter approach, all are established based on two pattern earthquakes as following:

- The historical earthquakes which have occurred over hundreds of years and have been explained in hand-written reports.
- Complete instrumental data which are recorded in a relatively short period of time.

Indeed, an important issue that should be considered in estimating the distribution and density functions of the magnitude is the amount of uncertainty and the imperfection of data. The methods which mainly were used to estimate the seismicity parameters (rate of seismic activity λ and the parameter b in Gutenberg-Richter relationship) were not suitable for imperfect historical data. One of the most appropriate methods for analyzing the historical part of the data catalog is the extreme-value distributions. But, the drawback of this method is that, it can be used for historical data not to analyze the instrumental data. Some researchers suggested that for estimating the seismicity parameters the historical data due to their incompleteness is to be removed from the data. Thus, the remaining part of catalog which is called the complete part of catalog can be used by any standard method to be analyzed. But, it is clear that this procedure is not also effective, because by removing the strong historical earthquakes which have occurred during a long period of time, the quantitative assessment of the recurrence of strong seismic events on the basis of observations over a short period of time will be burdened with large errors. However, the maximum likelihood estimation method which is used by Kijko for the first time is a perfect model for assessment of the seismicity parameters [8, 9]. This method is based on two fundamental assumptions:

- The occurrence of earthquakes is independent in time and place.
- The seismicity properties of the area under investigation are uniform.

This method that is presented as a computer program, for analysis of the historical earthquakes uses the extreme distribution and to analyze the instrumental earthquakes, uses the doubly truncated Gutenberg-Richter exponential distribution, and finally combines the results of two analyses. It is noted that the Kijko method, in analysis of instrumental part of catalog has the ability to divide them to some subcatalogs and consider different threshold magnitude level for each of them, separately. But this method has not suggested anything about the selection of the magnitude threshold level. By noting to the importance of selection of the magnitude threshold level in assessment of seismic hazard on one hand, and the basic assumption of the random occurrence of earthquakes in Kijko method on the other hand, in the present study, the instrumental earthquake sub-catalogs suggested by Alizadeh et al [44] are used. Because in that study not only the authors have used the Poisson model but also they have used the earthquake data of whole Iran, so it is very useful to be used here. Thus, the entire available earthquake data catalog for Amol area are divided to four subcatalogs including one historical and three instrumental earthquakes given in the following:

- Historical earthquakes (till 1900) with uncertainty 0.4 (Case # 1).
- Earthquakes recorded by analog devices (1900-1963), with uncertainty 0.3 and threshold magnitude threshold M_S=4.5 (Case # 2).
- Recent earthquakes (1964-2003) recorded with higher accuracy than previous earthquakes, with uncertainty 0.2 and magnitude threshold level M_S=4 (Case # 3).
- New earthquakes (2004-2017) recorded with very good accuracy and frequency, with uncertainty 0.1 and magnitude threshold level M_S=3.5 (Case # 4).

As noted earlier, the Kijko method has the ability to evaluate the seismicity parameters separately for each subcatalog of the considered earthquakes, but the best results can be obtained when the combination of all the subcatalogs are considered. The results of seismicity parameters using the above procedure for Amol by considering its surrounding area within a radius of 150 km are given in Table 5.

Table 5. Seismicity parameters obtained by Kijko 2000 computer program for Amol city

Catalogue	Parameter	Value	Data Contribution to the Parameter (%)			
			Case #1	Case #2	Case #3	Case #4
Only Historical Data	β	1.88	100	0	0	0
	λ(M_S=4.5)	0.43	100	0	0	0
Only 20th & 21th Centuries Data	β	2.06	0	36.0	37.7	20.8
	λ(M_S=4.5)	0.40	0	15.4	44.4	40.3
Combination of Historic & 20th & 21th Centuries Data	β	1.91	43.7	22.3	22.2	11.8
	λ(M_S=4.5)	0.44	17.5	12.7	36.6	33.2

It should be mentioned that in the table, β= bln10, in which b is the seismicity coefficient (Equation 2); and λ(m) is the annual mean rate of earthquake occurrence. In 1996, Tavakoli also performed a research study to obtain the seismicity parameters for the whole area of Iran, only using the instrumental data recorded in time period of 1929-1995, in which the province No. 20 includes the Amol zone, from which some of the results, for comparison, are given in Table 6 [22].

Table 6. Seismicity parameters calculated by Tavakoli for the province number 20

Province No.	Span of Time	Beta	Mmax	Lambda (MS=4.5)
20	1929-1995	2.32 ± 0.16	7.5 ± 0.9	0.33

By comparing Tables 5 and 6, it can be seen that the annual mean rate of earthquake occurrence obtained in the present paper is slightly higher than that of the Tavakoli's studies. The main reason of this difference can be related to the numerous number of earthquakes used in this paper compared with Tavakoli's studies (earthquakes that are recorded till 1995, the end of time period of earthquakes catalog, used by Tavakoli). Moreover, the difference between the seismicity coefficient presented in this paper and Tavakoli's studies can be resulted from neglecting the historical data by Tavakoli.

In the following, Figure 6 and Table 7 represent the return periods versus earthquake magnitude in Amol zone. It should be noted that in Iranian standard No. 2800, the design earthquake levels 1 and 2 are the earthquakes with probabilityies of exceedence of 10% and 2% in 50 years respectively, which by referring to the Figure 6, can be observed that the first one is an earthquake with M_S = 7.3 and the second one is an earthquake with M_S=7.9.

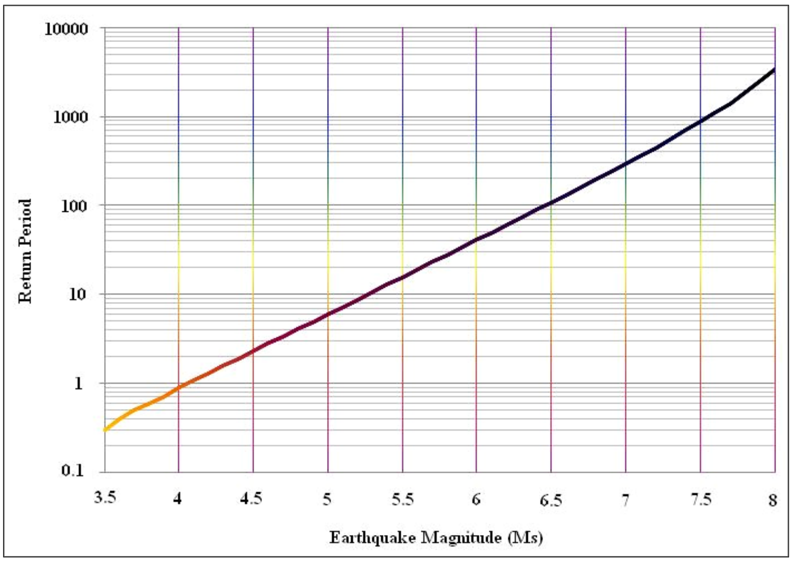

Figure 6. **Earthquake return period for Amol area in term on surface waves magnitude scale (M_S)**

Table 7. Probabilities of earthquake occurrence in terms of magnitude and the return period obtained for Amol zone

Earthquake Magnitude (M_S)	Return Period (year)	Probability of Earthquake Occurrence (to Percentage)			
		in one year	in 75 years	in 475 years	in 2475 years
3.5	0.3	100	100	100	100
4	0.9	67.9	100	100	100
4.5	2.3	35.3	100	100	100
5	6	15.3	100	100	100
5.5	15.6	6.2	99.2	100	100
6	40.9	2.4	84	100	100
6.5	108.4	0.92	49.9	98.7	100
7	295.2	0.33	22.4	80	100
7.5	871.9	0.11	8.2	42	94.2
8	3484	0.03	2.1	12.7	50.8

5. Zoning of Horizontal Peak Ground Acceleration for Amol Area

To estimate the peak ground acceleration in Amol, the Seisrisk III software, a software for seismic hazard analysis, is used. Although other software also could be used for this purpose, Seisrisk III is researcher's preference as the best software for evaluating the peak ground acceleration in Iran [26]. It is noted that for estimating the peak ground acceleration in probabilistic method, we need relationships that could link the attenuation rate of acceleration to the earthquake source parameters. These relationships are called conventional "Attenuation Relationships". In past decades, many empirical attenuation relationships are presented to evaluate the acceleration of earthquake strong ground motion for engineering purposes. In many cases, these relationships have the same overall shape with independent variables of magnitude and distance to the source. All of the represented models indicate to increase in certain parameters of the ground motion with increasing the value of earthquake magnitude, decreasing them by increasing distance from the source, and their dependence on the local features of site classified by different methods. For this purpose, the following general form is accepted by many researchers:

$$Y = b_1 . f_1(M) . f_2(R) . f_3(M, R) . f_4(P_i) . \varepsilon \qquad (3)$$

Which "Y" is the strong ground motion parameter that should be estimated; f_1 (M) is a function of magnitude; f_2 (R) is a function of distance; f_3 (M, R) is a joint function of magnitude and distance; f_4 (P_i) is representative function of path parameters, conditions of site or structure; and finally "ε" is a random variable to express the uncertainty exist in "Y".

These cases are different for each relation represented by researchers. Coefficients of these relationships can be obtained by curve fitting method on the observed data (in most cases the peak ground acceleration or spectral acceleration values). In many parts of the world, hundreds types of attenuation relationships have been introduced, while in many other areas, no attenuation relationship is presented for peak ground acceleration or spectral acceleration. The main cause of this deficiency is lack or shortage of database. In Iran country where is located in a very seismic prone area, despite existence of one of the largest accelerogram networks of the world and having a rich database of accelerograms, unfortunately few studies have been performed in this field. Nonetheless, many researchers believe that a given model for a specific region can be used in areas with similar characteristics [45]. But yet, using an attenuation relationship obtained from fitted experimental model for data of a specific region in other areas with different shell and tectonic profile is not permitted without the necessary modifications. The simplest and surest way to assess the suitability of the model, detailed knowledge of the Seismotectonics information, details of data of the earthquakes in the given area including magnitude, epicenteral distance and focal depth of earthquake, location, slope and interfaces of the causative fault, its mechanism, and also soil conditions of the site are necessary in study the fitting of earthquake data to the selected attenuation model.

To evaluate horizontal peak ground acceleration for this area, many attenuation relationships, in order to better adjustment to different part of Iran, are assessed and evaluated. Finally, for this purpose, eight different valid and useful attenuation relationships given for Iran are being used. Since most of the earthquakes occurred in Iran, including Amol region, have occurred in shallow ground, as well by noting to this point that some of these earthquakes are used in these relationships, it could be said that these relationships can be useful to assess the strong ground motion parameters in the other regions of Iran.

It should be noted that in order to get the perfect performance of these eight relationships, the results have been combined as a logic tree by giving a weighting coefficient to each of the relationships based on their accuracy and credibility. Then, from the weighted combination of the results obtained from the tree logic, the peak ground acceleration of the Amol and its suburbs is calculated. This logic tree of eight relationships with the weights assigned is expressed in Figure 7 [15-23].

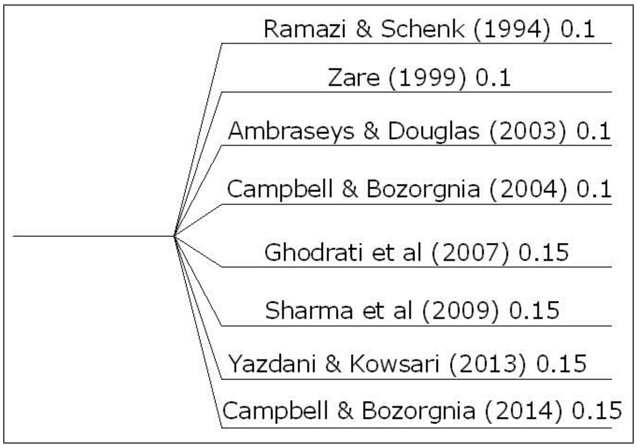

Figure 7. Logical tree of the attenuation relationships selected to estimate the horizontal peak ground accelerations

Using the above mentioned authentic, new and compatible attenuation relationships selected for the earthquakes occurred in the Amol area, the zoning maps of the horizontal peak ground accelerations are evaluated using the probabilistic seismic hazard analysis and the results are represented in Figures 8 and 9 for a risk of 10% and 2% in a life time 50 years (475 and 2475 years return period, similar to Iranian standard No. 2800) with damping ratio of 5% to its critical value. It can be seen that the values obtained for the peak ground acceleration in some areas of Amol are slightly higher than those given in Iranian standard No. 2800.

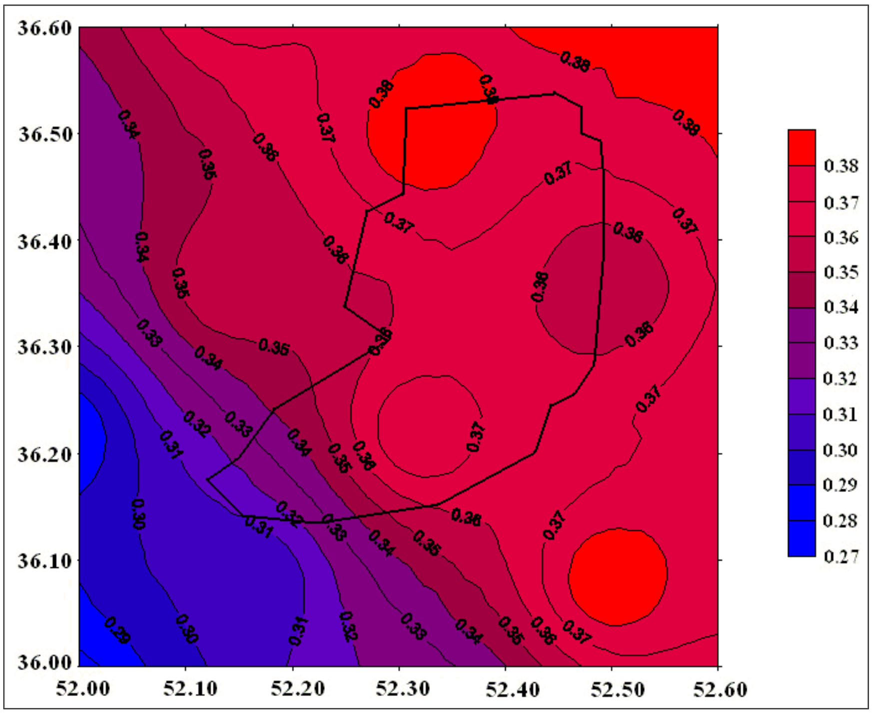

Figure 8. Seismic zoning map of Amol for horizontal peak ground acceleration for a risk of 10% in 50 years life time

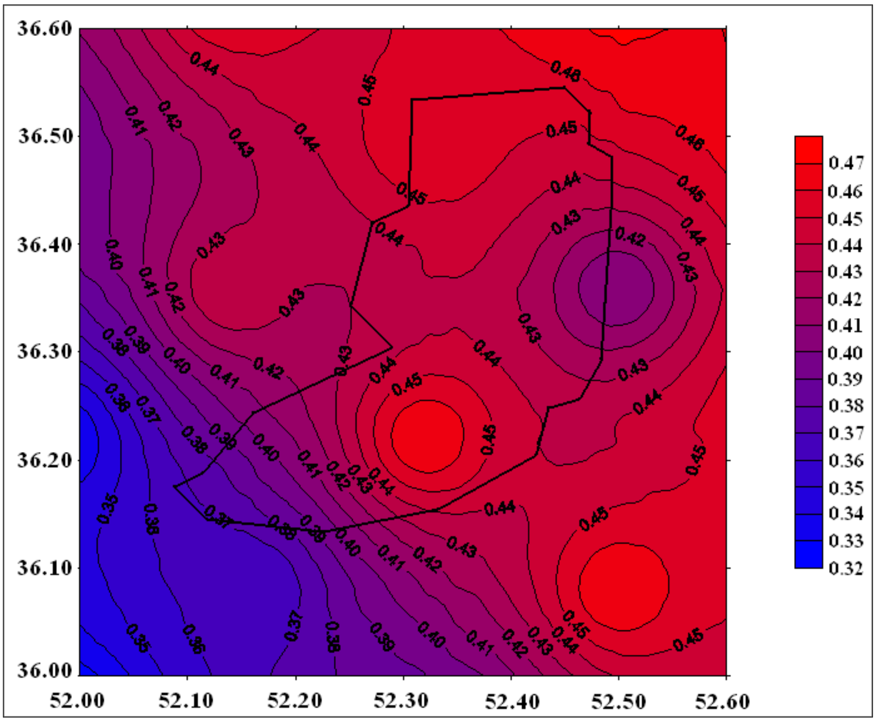

Figure 9. Seismic zoning map of Amol for horizontal peak ground acceleration for a risk of 2% in 50 years life time

6. Conclusion

Probabilistic seismic hazard analysis (PSHA) method is based on the identification and evaluation of seismic sources around the site under study, and defining a distribution to estimate any desired parameter of strong ground motion for the site during a certain period of time. The seismic sources can be selected within a radius of 100 to 300 km around the site based on the importance of existing structures. Many seismic studies have been carried out around the world till now, in which most of them was based on the well-known primary Gutenberg-Richter relationship. This relationship includes two basic parameters known as the "seismicity parameters". But this relationship alone is not sufficient for seismic hazard assessment, because it does not consider any limits for earthquake magnitude and may take large numbers, while the earthquake magnitude varies between some limited ranges. Another major problem in all of these studies was that there are two different seismic patterns: Earthquakes reported in historical writings that have occurred over a period of several hundred years, and the complete instrumental data that have occurred in a relatively short period of time.

Another important issue in this subject relates to the relationships needed to inter-convert different earthquake-magnitude scales. Different relationships have been proposed for this purpose in the world, but the vast majority of them are based on earthquakes occurred around the world. Although some of these relationships have been proposed based on earthquakes occurred in Iran, none of them covers different magnitude scales. Also, Alizadeh et al [26] by considering the multitude of Iran total data and of course their remarkable accuracy, reliable relationships exploit for assessment of seismicity in each favorite part of this area and even its adjacent lands.

Amol city is located in geographic range of 52.35º north longitude and 36.47º east latitude; in the Mazandaran province in north of Iran and along the Haraz river with a height of 76 meters above sea, with an area about 3000 square kilometers, and with a distance 70 km in west of Sari city center, 18 km south of Caspian sea, 6 km north of the Alborz mountain and 180 km northeast of Tehran.

The main objective of this paper is to evaluate the acceleration coefficient of the base by possible methods for Amol area. For this purpose, at the first the latest status of the major faults in the area, and the reported historical and instrumental earthquakes till 2017 A.D. within a radius of 150 km from the center of the city have been collected and studied. Then, after removal of aftershocks and foreshocks by using time and place windows method, seismicity parameters and earthquake return periods of the region for seismic hazard analysis are obtained by calculating the frequency of earthquakes using probabilistic relationships of Kijko 2000 computer program. From the numerical studies, it is found that due to the short period of instrumental earthquakes on one hand, and significant magnitudes of historical earthquakes on the other hand, in evaluating the seismicity coefficient "ß", a greater percentage of participation (about 44%) has been observed from historical earthquakes, while in evaluating the average earthquake rate "λ(m)", the most involvement percentage (about 37%) from the case#3 instrumental earthquakes (recorded from 1964 to 2003) was observed due to the greater number of the earthquakes in the catalog in this period. Moreover, by noting to the results obtained in this study, it is observed that likelihood of occurrence of high intensity earthquakes with a short-term return period will not be distant from mind.

Also, it can be seen that the annual mean rate of earthquake occurrence obtained in the present paper is slightly higher than that of the Tavakoli's studies. The main reason of this difference can be related to the numerous number of earthquakes used in this paper compared with Tavakoli's studies (earthquakes that are recorded till 1995, the end of time period of earthquakes catalog, used by Tavakoli). Moreover, the difference between the seismicity coefficient presented in this paper and Tavakoli's studies can be resulted from neglecting the historical data by Tavakoli. Moreover in Iranian standard No. 2800, the design earthquake levels 1 and 2 are the earthquakes with probabilityies of exceedence of 10% and 2% in 50 years respectively, which these values for the first level is about M_S =7.3 and for the second level about M_S=7.9.

Finally, seismic zoning maps of horizontal peak ground acceleration coefficient for Amol city and its suburbs have been obtained by using Seisrisk III hazard analysis software. By comparing the results obtained in this paper, it can be seen that the values obtained for the peak ground acceleration in some areas of Amol are slightly higher than those given in Iranian standard No. 2800. It is noted that the value of peak ground acceleration given in standard No. 2800 for the design earthquake level 1 in Amol and its suburbs is 0.3. It is essential to note that the horizontal peak ground acceleration values increase from south to north, especially northeastern. This increase represents more seismicity active parts of the northeastern of this zone in comparison with that of the south parts and it should be considered seriously in the construction of various and important buildings, as well as the restoration of numerous monuments of this area.

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