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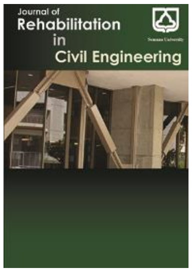

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Seismic Hazard Assessment and Determination of Maximum Design Base Acceleration of Yazd

A. Asadi[1], Sh. Neshat[2*] and K. Barkhordari[3]

1. Assistant Professor, Department of Civil Engineering, Yazd University, Yazd.
2. Master of Science.
3. Assistant Professor, Department of Civil Engineering, Yazd University, Yazd, Iran.

* Corresponding author: *sharareh_neshat@yahoo.com*

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ABSTRACT

According to Iranian code of practice for seismic resistant design of buildings standard No. 2800, Yazd is located in the place with the medium earthquake hazard. Due to the position of Yazd with many historical and important buildings, maintaining these traditional heritages is an important task in civil engineering field. On account of these mentioned valuable buildings and region potential in constructing the new vital structures such as Yazd University, exact regional seismicity surveying and seismic hazard assessment would need to be scrutinized. For this purpose a collected catalogue, containing both historical and instrumental events is used covering the period from the 4th century BC to 2009. Seismic sources are modeled and recurrence relationship is obtained. The method proposed by Kijko and Tavakoli were employed for determination of seismicity parameters. Then logic tree method and weighted attenuation relationships were applied. Probabilistic seismic hazard assessment is carried out using SEISRISK III for Yazd University site. At the end, Peak Ground Acceleration (PGA) of the studied area for a return period of 475 and 2475 years for 10% and 2% probability of exceedance in life cycle of 50 years is evaluated equal to 0.25g and 0.35g.

1. Introduction

Iran is situated over one of the seismic zones of the world, the Himalayan-Alpide seismic belt, which has experienced catastrophic earthquakes lead to huge financial and human life losses. Exact assessment of seismic hazard analysis for Yazd, the world's second historical city, is essential due to some major reasons:

- There are many valuable historical buildings located in Yazd, which attract many tourists.
- Some people still live in historical texture which is very vulnerable to even a microseism.
- Yazd is one of the developing cities and there is a great need for constructing some significant projects which need the evaluation of the severity of earthquake occurrence.

The city of Yazd is situated on the Iranian central desert and lie roughly on the middle of central plateau, the areas among Alborz and Zagros Mountain. Yazd province is located between latitude 29 degrees 48 minutes and 33 degrees 30 minutes north and longitude 52 degrees 45 minutes and 56 degrees 30 minutes east. The maximum length and width of Yazd are about 380 km and 350 km, respectively. It has an area of 7200 Square kilometers.

"A" is the design base acceleration over bedrock according to the Iran's seismic code [1]. The Iranian seismic code suggests the value of A=0.25g for the Yazd. In this work, an effort has been made to update the design base acceleration for the calculation of earthquake equivalent static forces in the return period considered by mentioned code using newer and more comprehensive data and new scientific research. In addition, the results are provided for an earthquake with a return period of 2475 years in order to be applicable for designing critical structures.

2. Seismotectonic structure of Yazd

According to the earthquake data of Iran, most activities are concentrated along the Zagros fold thrust belt in comparison to the central and eastern parts of Iran [2]. The Iranian tectonic plate in the Middle East has an effect on seismotectonic condition of Yazd region.

Several studies have been done on the seismotectonic structures of Iran in the past. Stocklin [3], Takin [4], Berberian [5] have suggested simplified divisions of nine, four, and four regions, respectively. Nowroozi [6] divided Iran into twenty-three division seismotectonic provinces. In another study, Tavakoli [7] divided Iran into 20 seismotectonic provinces in a new model using a modified and updated catalogue of notable earthquakes in Iran.

The significant active faults in Yazd region include: Mehriz, North Yazd- South Ardakan, Taft, Tezerjan, Cheshmehmoosa, Chahkhavar-Kooyelaghaz, Shahrbabak, Rafsanjan, Anar, Ravar, Bahabad, Dehshir and Baft faults [8]. Active faults and their lengths have been shown in Table 1.

Table 1. Active faults of Yazd and its vicinity

No.	Fault	Length(km)
1	Mehriz	22
2	North Yazd- South Ardakan	60
3	Taft-Tezerjan	60
4	Cheshmehmoosa	40
5	Chahkhavar-Kooyelaghaz	*50*
6	Shahrbabak	250
7	Rafsanjan	130
8	Anar	100
9	Ravar	80
10	Bahabad	60
11	Dehshir and Baft	350

3. Seismicity of Yazd

The seismic data in Yazd is classified as historical earthquakes, the earthquakes occurred before 1900, and instrumentally recorded earthquakes, the earthquakes after

1900. The instrumentally recorded data were obtained using analogue and digital instruments. Since earthquakes are identified as the most catastrophic natural events, they have been reported and recorded in historical notes. Therefore, it should be considered that the validity of our knowledge of past earthquakes is based on authenticity of the source of information. The magnitudes of the historical earthquakes are estimated based on damage, extent of the region in which the earthquake was felt or some other factors which can be compared with the seismic data obtained from the recent earthquakes. Reports of seismic data in this regards were provided by Researchers like Berberian [9], moinfar [10], Ambraseys and Melville [11].

In general, for Yazd 9 earthquakes with magnitudes greater than M_s =4.0 were reported over the time span of the studied catalogue, the maximum of which occurred in 1459 with a magnitude of M_s =6.6. Table 2 represents the historical earthquakes in Yazd.

Table 2. Historical earthquakes in Yazd

No.	Year	Month	Day	M_s
1	1344	-	-	5.7
2	1459	-	-	6.6
3	1591	-	-	5.9
4	1752	-	-	5
5	1765	4	23	4
6	1784	3	1	4
7	1824	6	25	6.4
8	1844	5	12	6.4
9	1853	5	4	6.5

More precise seismic data was gathered in Yazd and its vicinity after 1900 due to installation of earthquake-recording devices. This seismic data were collected from the International Seismological Center (ISC) and the National Earthquake Information Center (NEIC).

4. Seismicity parameters of Yazd

Gathering the seismic data occurred in Yazd and its vicinity and applying probabilistic methods are major steps in seismic assessment. For this reason the earthquake catalogue in a radius of 200 km has been collected, considering that the earthquakes follow a Poisson distribution. Then Kijko method [12] was used to calculate seismic parameters, recurrence intervals, and the probability of the occurrence of earthquakes.

4.1. Earthquake catalogue

For collecting seismicity data, a list of earthquakes was gathered and selected in a radius of 200 km around Yazd. As mentioned in section 3, this collection is based on historical and instrumental records. In order to assume that the earthquakes have a nonrandomized nature and follow a Poisson distribution, the incorrect reported events from the data, aftershock and foreshock should be eliminated from the earthquake catalogue. Aftershock and foreshock removal could be done in two methods: (1) manual (2) time and space window algorithm (Knopoff, 1974)[13]. In manual method, aftershock and foreshock are removed in term of time-space domains and engineering judgment. This method is low speed and demands a lot of calculation. In addition, it requires a high degree of skill and experience. In the second method, aftershock and foreshock are removed by time and space domains windowing procedure. It works with the help of fixed and also variable windows. In this paper, the aftershock and foreshock were removed using Knopoff software worked with variable windows. The refined catalogue contains earthquake magnitudes in different scales. The magnitude scales in this catalogue include Richter local magnitude scale (M_L), surface-wave magnitude scale (M_s) and body-wave magnitude scale (m_b). All other magnitudes were converted to Ms. For converting m_b to M_s, the equation presented by the Iranian Committee of Large Dams, IRCOLD [14], was employed, Eq. 1:

$$M_s = 1.2m_b - 1.29 \quad (1)$$

4.2. Determination of seismicity parameters

To determine the seismicity of Yazd, seismicity parameters such as the maximum expected magnitude, M_{max}, activity rate, λ, and the b value of the Gutenberg-Richter relation should be calculated. In order to calculate the seismic parameters, the occurrence of earthquakes and the relationship between their magnitudes and frequencies were considered. One of the most useful methods for evaluation the seismic coefficients is Gutenberg and Richter relationship [15]. This relationship shows the logarithmic relationship between cumulative frequency of earthquake occurrence and its magnitude, presented in Eq. 2:

$$logN_c = a - b \times M_i \quad (2)$$

Where N_c is the number of earthquakes having magnitudes greater than M_i, M_i is the earthquake magnitude, a and b are constants and related to seismicity of considered area. It is essential to consider the fact that these values would change with the variation of time range the data collected. To solve this problem, the number of earthquakes having magnitudes greater than M during one year have been used in Eq. 2. The Eq. 2 is rewritten in Eq. 3:

$$logN = a - b \times M_i \quad (3)$$

$$N = \frac{N_c}{T}$$

Where T is time range which the data is collected.

Fig. 1. shows the logarithmic relationship between cumulative frequency of earthquake occurrence in Yazd and its magnitude. The values of a and b were calculated 0.5722 and 3.9432, respectively.

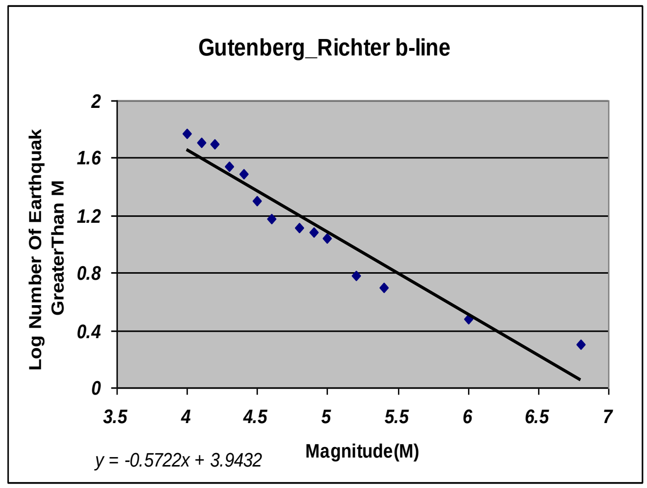


Fig. 1. Gutenberg-Richter (b-line)

These parameters significantly affect the results of earthquake hazard, therefore, in this paper the new method of Kijko [12] based on the probabilistic method of maximum likelihood estimation and the double extreme distribution function of Gutenberg-Richter is used.

4.2.1. Evaluation of seismicity parameters using Kijko [12] method for Yazd

The composition of historical and instrumental data has been applied in Kijko [12] method. Due to uncertainty about reported earthquakes in Iran, the maximum likelihood estimation could be appropriate solution for evaluation of seismicity parameters. In this paper, the seismic parameters were calculated for Yazd city in a radius of 200 km. In addition, uncertainties about earthquake magnitudes were considered in the calculation.

The Kijko [12] computer program applies the maximum likelihood estimation probabilistic method with the use of extreme distribution function for the historical events with low precision and large magnitudes, and the double truncated Gutenberg-Richter distribution function for the instrumentally recorded data. In this paper, three types of earthquakes include historical (events before 1900), instrumentally recorded from 1900 to 1963 and instrumentally recorded from 1964 to 2005 were used. The uncertainty coefficients for these three types were considered 0.4, 0.2 and 0.1, respectively. The threshold magnitude was assigned 3.9.

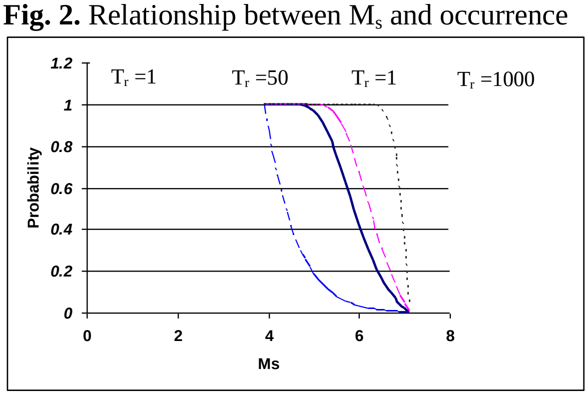
The seismicity parameters using Kijko [12] computer program were presented in table 3. The calculated M_{max} value for Yazd is 7.11.

Table 3. Seismicity parameters using Kijko [12] method for Yazd

Location	M-max	s(3.9)	b	Beta
Yazd	7.11	0.45	0.73	1.69

The relationship between M_s and occurrence probability in 1, 50, 100, 1000 year/years has been shown in Fig. 2.

Fig. 2. Relationship between M_s and occurrence



4.2.2. Parameters using Tavakoli [7] calculation for Iran

Tavakoli [7] has studied the seismotectonic condition of Iran and proposed a seismicity map for Iran. In this map, Iran has been divided into 20 provinces. According to tavakoli [7] studies, Yazd is located in province No. 9. Presented seismicity parameters for Yazd is shown in table 4.

Table 4. Seismicity parameters using tavakoli [7]

Zone	Span of time	b(KS)	M_{max}	$M_{(obs)}$	n(m>4.5)
9	1922-1995	0.82	7.3	6.8	0.27

The seismicity parameters using Tavakoli [7] calculation were presented in Eq. 4:

$$log(n(m)) = 3.121 - 0.82m \quad (4)$$

Where n(m) is the number of earthquakes having magnitudes greater than m, m is the earthquake magnitude.

5. Seismic hazard assessment

Due to uncertainty about earthquake include earthquake magnitude, occurrence time, hypo central location, earthquake's characteristic, site effect, site and structural response, seismic hazard is used to estimate the expected occurrence of future earthquake [16]. Therefore, probability theory should be applied to predict the seismic hazard [17].

The steps for seismic hazard analysis can be classified in five steps: (1) geologic and tectonic studies and collecting historical and instrumental earthquakes, (2) seismic source modeling, (3) determination of seismicity parameters, (4) evaluation of attenuation relationships for peak ground acceleration, and (5) evaluation of design maximum acceleration.

5.1. Attenuation relationships

The attenuation relationship is one of the fundamental items in seismic hazard assessment which clarifies the reduction in peak ground motion (velocity, displacement, acceleration) due to wave passing in soil. This reduction is defined for an earthquake of magnitude (M) occurred in distance (R) from the epicenter. The attenuation relationship is affected from some factors such as fault mechanism, geological conditions, source specifications, magnitude, wave propagation and etc.

Since the accuracy of Iran's data is not sufficient, different attenuation relationships should be applied. In this research, GhodratiAmiri and Manochehrian [18], Ambraseys and Bommer [19] and Sarma and Srbulov's [20] relationships were employed and for combination of results the logic-tree method was used. GhodratiAmiri and Manochehrian's [18] relationship was based on the reported earthquakes recorded in Iran. This relationship covered the local condition. Other relationships were derived due to earthquakes happened in different parts of the world. Ambraseys and Bommer's [19] attenuation relationship was suggested based on the earthquakes in Europe, Turkey, Iran, Pakistan and Palestine with distance less than 200 km from the source to the strong ground motion recording stations. This relationship covered regional conditions. Sarma and Srbulob's [20] attenuation relationship was also based on the recorded accelerograms of shallow earthquakes in western America, Europe and Middle East [21]. This relationship based on world conditions.

5.2. Relationship between maximum expected magnitude and fault rupture length

Estimating the maximum earthquake magnitude in each state depends on the recognizing of the seismotectonic and geotectonic behavior. According to the accumulation of the strain energy in faults and occurrence mechanism of the tectonic earthquakes, fault length is considered one of the main characteristic of an earthquake. In general, the relationship between maximum expected magnitude (M) and fault rupture length (L) can be written as:

$$logL = a + bM \tag{5}$$

Where a and b are constant coefficients. The rupture length is a percentage of the fault length, which causes the earthquake and varies for different fault lengths. This percentage is usually considered from 30% to 50% of the total length of the fault [22]. According to studies done by Nowroozi [23] over ten severe earthquakes in Iran, the Eq. 6 was offered.

$$M_s = 1.259 + 1.244log(L) \tag{6}$$

Where M_s is the surface magnitude and L is the rupture length in meter.

5.3. Logic tree

Most of the input data in probabilistic seismic hazard analysis (PSHA) such as fault dimensions, recurrence rates, maximum magnitudes, attenuation relationships, etc are calculated from limited data or individual judgments. Logic tree is usually used in PSHA to retrieve these uncertainties. In this method, these parameters are weighted by some coefficients; the lower coefficient shows the lower accuracy. In logic tree, the uncertainty in attenuation relationships and seismicity parameters was reduced by the product of the assigned weight. In this paper, the considered weights for both of the Kijko [12] and Tavakoli's [7] seismicity parameters were 0.5. In addition, the offered weights for GhodratiAmiri and Manochehrian [18], Ambraseys and Bommer [19], Sarma and Srbulov's [20] attenuation relationships were 0.4, 0.35, 0.25, respectively. The reason for using the three different weights to attenuation relationships is that the two latest attenuation relationships are global and based on data of other countries of the world. Therefore, the weighting coefficients in these relationships are considered lower and for GhodratiAmiri and Manochehrian's [18] relationship, which is established on Iran's data, it is considered 0.4. Considering the advantages and disadvantages of each method, it is obvious that the application of both methods in the calculations and using logic-tree method is been most beneficial.

5.4. Probabilistic seismic hazard analysis (PSHA)

Probabilistic seismic hazard assessment was performed by SEISRISK III [24] to calculate Peak Ground Acceleration. This program is based on the assumption that the site acceleration follows the Poisson distribution with a mean annual rate. It was run for three mentioned attenuation relationships and the Peak Ground Accelerations (PGA) of the studied area for a return period of 475 and 2475 years for 10% and 2% probability of exceedance in life cycle of 50 years were calculated. Seismic hazard curve is shown in Fig. 3.

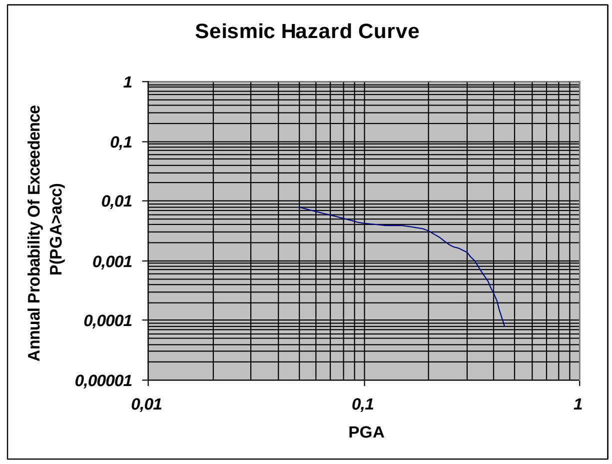


Fig.3. Mean seismic hazard curve

This paper studied seismic hazard of Yazd city and its vicinity based on probabilistic approach. Studies show that the interested area has the medium seismic induction. Probabilistic seismic hazard analysis offers the Peak Ground Accelerations (PGA) equal to 0.25g and 0.35g for an earthquake with a return period of 475 and 2475 years for 10% and 2% probability of exceedance in life cycle of 50 years, respectively. This value is justifiable compared to the result of Iranian code of practice for seismic resistant design of buildings standard No. 2800 [1] which offers the PGA equal to 0.25g for an earthquake with a return period of 475 years.

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