Earthquakes and Structures, *Vol. 18, No. 2 (2020) 223-231*
DOI: https://doi.org/10.12989/eas.2020.18.2.223

Estimation of probabilistic hazard for Bingol province, Turkey

Bilal Balun[1a], Ömer Faruk Nemutlu[2b], Ahmet Benli[*3] and Ali Sarı[4c]

[1]*Centre for Energy the Environment and Natural Disasters and Department of Architecture, Bingol University, Bingol, Turkey*
[2]*Centre for Energy the Environment and Natural Disasters and Department of Civil Engineering, Bingol University, Bingol, Turkey*
[3]*Department of Civil Engineering, Bingol University, Bingol, Turkey*
[4]*Department of Civil Engineering, Istanbul Technical University, Istanbul, Turkey*

(*Received October 12, 2019, Revised December 17, 2019, Accepted December 25, 2019*)

Abstract. Due to the fact that Bingöl province is at the intersection of the North Anatolian Fault and the Eastern Anatolian Fault, the seismicity of the region is important. In this study, probabilistic seismic hazard analyzes (PSHA) were conducted to cover the boundaries of Bingöl province. It occurred since 1900, the seismicity of the region was obtained statistically by considering the earthquake records with a magnitude greater than 4 and the Gutenberg-Richter correlation. In the study, magnitude-frequency relationship, seismic hazard and repetition periods were obtained for certain time periods (10, 20, 30, 40, 50, 75 and 100 years). Once a project area determined in this study, which may affect the peak ground acceleration according to various attenuation relationships are calculated and using the Turkey Earthquake Hazard Map, average acceleration value for Bingöl province were determined. As a result of the probabilistic seismic hazard analysis, the project earthquakes with a probability of exceeding 50 years indicate that the magnitude of the project earthquake is 7.4 and that the province is in a risky area in terms of seismicity. The repetition periods of earthquakes of 6.0, 6.5, 7.0 and 7.5 are 42, 105, 266 and 670 years respectively. Within the province of Bingöl; the probability of exceeding 50 years is 2%, 10% and 50%, while the peak ground acceleration values are 1.03 g, 0.58 g and 0.24 g. As a result, probabilistic seismic hazard analysis shows that the seismicity of the region is high and the importance of considering the earthquake effect during construction is emphasized for this region.

Keywords: seismic hazard analysis; PSHA; Gutenberg-Richter correlation; peak ground acceleration; Bingol

1. Introduction

In Turkey which is located in the earthquake zone, Bingöl, which is the intersection point of the North Anatolian and Eastern Anatolian fault lines, has experienced severe earthquakes causing significant damage and loss of life and property throughout history. An earthquake with a magnitude of 6.8 occurred at 18:43 pm on May 22, 1971, and an earthquakes of 6.2 magnitude occurred at 03:29 am local time of May 1, 2003 are examples. In the earthquake of May 1, 2003, there were 177 deaths and 520 injuries and 17429 damaged buildings were identified as a result of the works carried out by the General Directorate of Disaster Affairs. It was determined that the heavily damaged and demolished buildings were in the order of 17%, 55% of the existing building stock, 56% of the houses and 65% of the workplaces were damaged. For this reason, seismic hazard analyzes have been carried out in order to predict the effect of the earthquakes that may occur in the future (Dogangun 2004, Milkereit *et al*. 2004, Ceken *et al*. 2014, Akkar *et al*. 2005, Ulusay and Aydan 2005). When considering an evaluation of seismic activity in Turkey, Bingöl province is one of the most active regions in terms of seismic activity. By definition, seismic hazard is defined as the probability of exceeding a certain level within a prescribed time by the parameters related to the earthquake magnitudes and the ground movements to which the field is exposed. It is not usual to predict the location, time, size, and other parameters of future movements in a moving place in terms of seismic hazard. In seismic hazard analysis, the aim is to calculate the probability of an earthquake occurring in the future by combining the previously occurring earthquake data with geological, seismic and other information. In terms of civil engineering, the most important points for earthquake engineers are the determination of the values related to these effects at a certain construction site (Sayin *et al*. 2014, Celep *et al*. 2011, Sayin *et al*. 2013). Due to this uncertainty and the seismicity of the region, the probability of exposure to the current hazard and large scale earthquakes leads to probabilistic hazard analysis. In contrast to the deterministic hazard analysis, which is another approach used in seismic hazard analysis, the probabilistic seismic hazard analysis approach is a more consistent approach because of the higher number of uncertainties. In the analysis of structures such as nuclear power plants, hospitals, bridges and dams, which are likely to lead to substantial losses and major catastrophes, the need for a seismic hazard analysis is required. In this field, various researchers have conducted studies on this subject

*Corresponding author, Ph.D.
E-mail: ahbenli@hotmail.com
[a]Ph.D.
E-mail: bbalun@bingol.edu.tr
[b]Ph.D. Student
E-mail: ofnemutlu@bingol.edu.tr
[c]Ph.D.
E-mail: asari@itu.edu.tr

http://www.techno-press.org/?journal=eas&subpage=7
ISSN: 2092-7614 (Print), 2092-7622 (Online)

Fig. 1 Borders and Districts of Bingöl Province (2019)

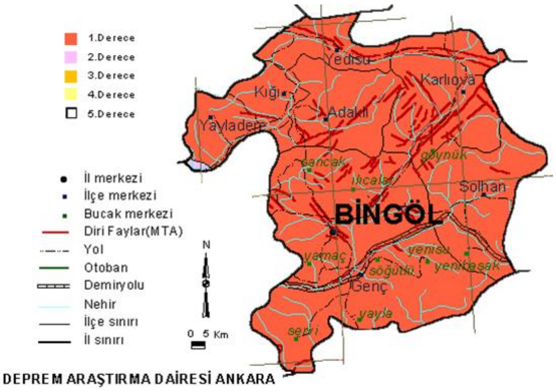

Fig. 2 Effective Faults on Bingöl Province (Ulusay and Aydan 2005, 2019)

Table 1 Some important earthquakes that have caused major losses on the North Anatolian Fault and the East Anatolian Fault (2019)

Name	Date	Epicenter	Magnitude	Effective Fault
E-1	17.08.1949	Elmalıdere	6.9(Ms)	KAF
E-2	19.08.1966	Varto	6.8(Ms)	KAF
E-3	26.07.1967	Pülümür-Kığı	6.0(Ms)	KAF
E-4	13.03.1992	Erzincan	6.8(Ms)	KAF
E-5	22.05.1971	Bingöl	6.8(Ms)	DAF
E-6	7.07.1957	Kiğı	5.1(Ms)	KAF-DAF triangel
E-7	24.04.1968	Ç an-Kiğı	5.1(Ms)	KAF-DAF triangel
E-8	5.12.1995	Kiğı	5.7(Ms)	KAF-DAF triangel
E-9	3.02.2003	Pülümür	6.1(Mw)	KAF-DAF triangel
E-10	1.05.2003	Bingöl	6.4(Mw)	KAF-DAF triangel

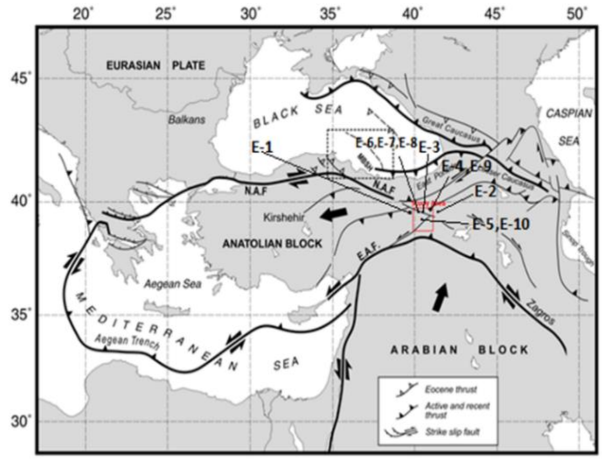

Fig. 3 Tectonic map of Bingol and study area (modified from Rangin *et al*. 2002), (Rangin *et al.* 2002)

(Görgün and Ural 2018, Karaca 2017, Harman 2016, Işık *et al*. 2012, Sezer 2008, Yücemen 2011, Kartal *et al*. 2014, Ince and Kurnaz 2018, Kartal *et al*. 2014, Mahsuli *et al*. 2019, Sokolov *et al*. 2017, Ashadi *et al*. 2015, Pailoplee and Charusiri 2016, Bwambale *et al*. 2015, Mantyniemi *et al*. 2003, Sil *et al*. 2013, Ayele 2017, Naidu, *et al*. 2018, de Almeida *et al*. 2019, Anbazhagan *et al*. 2009, Andric and Lu 2017, Mahmoudi *et al*. 2016). While probabilistic seismic hazard analysis is being carried out, those who work in this field divide the period before 1900 into a historical period and the period after 1900 as an instrumental period and examine them in two periods (Sezer 2008). In this study, data belonging to instrumental period after 1900 were used. Fig. 1 and Fig. 2 show the effective faults on Bingöl province (Ulusay and Aydan 2005, 2019).

1.1 Tectonic and geology

The province of Bingöl is located in the Bingöl-Karlıova-Erzincan region, which is one of the regions where faults are most active in our country. The North Anatolian Fault and the East Anatolian Fault are two important faults in the active tectonic roof. In this triangle, Bingöl province is limited to the Erzincan pull-apart basin along the North Anatolian Fault in the north, and on the south to the rising Gökdere elevation in the compression jump zone between the Eastern Anatolian Fault and Palu-Bingöl. In the East-West direction, the effective section of the North Anatolian Fault, which extends over an entire length of 1600 km, is approximately 120 km. The eastern Anatolian fault, which is 580 km long, is approximately 65 km long in the Bingöl borders. In the Bingöl-Karlıova-Erzincan triangle bounded by the North Anatolian Fault and East Anatolian Fault transform faults, these two main faults have been cross-developed and numerous active faults have been mapped. Of these, the ones developed as the arms separated from the North Anatolian Fault to the south-west are left-sided strike-slip and extend parallel to the Eastern Anatolian Fault. According to the information available, Ovacık Fault, Pülümür Fault, Sancak Uzunpınar Fault Zone to the south of the Munzur Mountains is the most active active faults in this triangle. The Bingöl-Karakoçan fault zone extending in the north-west and south-east direction and the right-hand direction crosses to the East Anatolian Fault. In the west of the Karlıova basin, which is the easternmost part of the Anatolian plateau and between the North Anatolian Fault and the East Anatolian Fault, these two faults are connected to the west and concave to the east and the eastern blocks are followed by the normal component faults (Ulusay and Aydan 2005, 2019). Table 1 shows some important earthquakes that have caused major losses on the North Anatolian Fault and the East Anatolian Fault (Ulusay and Aydan 2005, 2019). Fig. 3 shows the tectonic map and study area of Bingol (Rangin *et al*. 2002).

1.2 Seismic hazard analysis

The purpose of the seismic hazard analysis is to calculate the parameters (acceleration, displacement and velocity) of the ground and the structure at the construction site at a given point, for an earthquake effect likely to occur in the future (Yücemen 2011). The seismic hazard analysis generally falls under two headings; Deterministic seismic hazard analysis (DSHA) and probabilistic seismic hazard analysis (PSHA), (Yücemen 2011, Kayabalı 1995, Mulargia *et al*. 2017, Rehman *et al*. 2013). In this study, probabilistic seismic hazard analysis was used. Deterministic seismic hazard analysis was given for information.

- All earthquake sources in the region should be defined in terms of earthquake potential and source geometry.
- For each earthquake source considered, the distance parameters between the source and the affected area should be determined, the shortest distance from these distances should be determined and the distances to the epicenter and hyposantr distances should be calculated.
- Then, for the region to be studied, it is necessary to determine the greatest earthquake ground motion that will affect this region
- Seismic hazard analysis is completed by determining the seismic hazards to be affected by the region for the determined strong ground motion

1.2.2 Probabilistic seismic hazard analysis

The probabilistic approach is more preferred than the deterministic approach because the uncertainties found in the analysis of seismic hazard affect the calculations (Mulargia *et al*. 2017, Rehman *et al*. 2013). These uncertainties can be listed as the size of the earthquake, the range of repetition, the location of the earthquake, the characteristics of the ground motion. In probabilistic seismic hazard analysis, the aim is to obtain a probable ground motion variable or earthquake intensity in a given region (Yücemen 2011). The probabilistic seismic hazard analysis generally includes the following steps

- Determination of all seismic sources and geometry and their characterization
- Distribution of earthquake magnitudes, seismicity of each zone (Magnitude-Frequency relationship)
- Selection of attenuation relationships and determination of ground motions in the study area
- To obtain the probability that the ground motion parameter will be exceeded within a certain time period

It is a necessity of the probabilistic approach to take into account the time distribution of earthquake formation in calculating the probability of different hazards in a given time period. There are various stochastic methods in use for this. It is the most widely used Poisson model. According to this model, the occurrence of earthquakes is independent of time and space. In the Poison probability model, distribution has three characteristics: Independence, Regularity and Stability. Summarizing these characteristics, the probability that the two seismic events are at the same time and position approaches zero in this model (Mulargia *et al*. 2017, Rehman *et al*. 2013). Published by AFAD (Prime Ministry Disaster and Emergency Management Authority) in 2018 Turkey Earthquake Hazard Map, which works carried out simultaneously with the Turkey Earthquake Earthquake Code-2018 (Fig. 4), is based on the probabilistic seismic hazard analysis principles. The earthquake hazard map, which has been used instead of the earthquake zone map, has a probabilistic approach and has a more realistic approach than the earthquake zone concept because it provides coordinated data flow (2019).

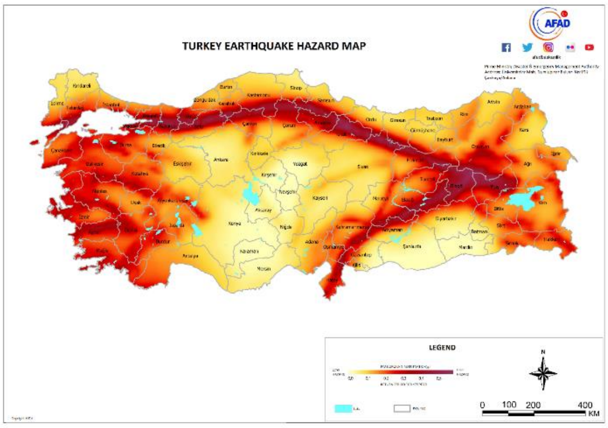

Fig. 4 Turkish Earthquake Hazard Map (AFAD) (2019)

2. Method and results

In this study, probabilistic seismic hazard analysis and the seismicity of Bingöl were investigated. The earthquake data of the region were obtained from the web site of AFAD (2019). Earthquakes occurred in Bingol province with a magnitude of 4 and above from 1900 to the present. A total of 101 seismic data with a size of 4 and above were collected and some of these are given in Table 2. Earthquakes larger than 4 occurred in Bingol since 1907 are shown in the Fig. 6. The distribution of these earthquakes in Bingöl province is given in Fig. 5. It is seen that the earthquakes occurred mostly in the early 1970s and early 2000s. The 1971 and 2003 Bingöl earthquakes were 6.80 and 6.30, respectively, with a period of approximately 30 years between these two earthquakes. The probabilistic seismic hazard analysis based on the Poisson model was performed in order to evaluate the seismic hazard potential of the Bingol Province in this study. In this context, 101 earthquakes (main shocks) with moment magnitudes (*Mw*) equal or greater than 4.0 that occurred between 1907 and Eastern Anatolian fault but the major earthquakes on these faults are not far enough to affect the region. In this study, the first step of probabilistic seismic hazard analysis and magnitude-frequency relationship was investigated by Gutenberg and Richter correlation. Gutenberg and Richter 1944 proposed a statistical method that includes the magnitude-frequency relationship between earthquakes in the past and future earthquakes (Eq. (1)).

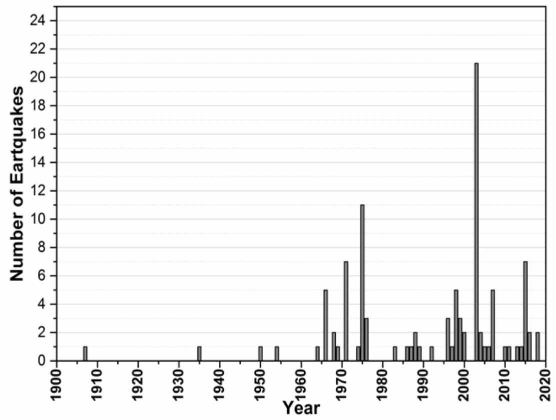

Fig. 5 Distribution of earthquake numbers for Bingöl province by years ($M \geq 4$)

Table 2 Some earthquakes occurred in Bingol and its districts during the instrumental period (2019)

Year	Latitude	Longitude	Area	Depth (km)	M
1907	39.3000	40.4000	Kiğı	10.00	4.90
1935	39.2000	40.6000	Adaklı	10.00	4.60
1950	39.3000	41.0000	Karlıova	10.00	4.90
1954	39.0300	40.9700	Solhan	10.00	5.40
1964	38.6600	40.1800	Genç	65.00	4.20
1966	39.1650	40.7620	Karlıova	18.70	5.40
1968	39.1890	40.3190	Kiğı	11.80	5.00
1969	38.9000	41.0000	Solhan	169.00	4.30
1971	38.8500	40.5200	C.Center	3.00	6.80
1974	39.0470	40.6469	C.Center	17.30	4.20
1975	38.6470	40.7504	Genç	44.90	4.70
1976	38.5710	40.6460	Genç	21.90	4.80
1983	38.7136	41.0370	Solhan	10.00	4.50
1986	38.9065	40.3087	C.Center	9.00	4.30
1987	39.1513	40.5000	Adaklı	10.00	4.20
1988	39.2393	40.3382	Kiğı	10.00	4.30
1989	38.7669	40.8036	Genç	10.00	4.30
1992	39.2468	40.3812	Adaklı	33.00	4.20
1996	38.5400	40.3000	Genç	10.00	4.00
1997	39.2949	40.7192	Adaklı	46.10	4.10
1998	39.1590	40.3250	Kiğı	15.10	4.40
1999	39.2650	40.2040	Kiğı	36.30	4.30
2000	38.5510	40.2800	Genç	38.80	4.50
2003	39.0100	40.4600	C.Center	10.00	6.30
2004	39.0200	40.4080	C.Center	1.60	4.30
2005	39.2469	41.1110	Karlıova	10.00	4.10
2006	39.0980	40.3610	C.Center	17.10	4.40
2007	39.2480	41.1220	Karlıova	12.50	5.30
2010	39.0662	40.8078	C.Center	18.15	4.20
2011	39.2400	40.4100	Adaklı	5.00	4.20
2013	39.0063	41.1835	Solhan	15.64	4.40
2014	38.8356	40.9686	Solhan	5.24	4.10
2015	39.2610	40.2170	Kiğı	10.66	5.30
2016	39.0118	40.7121	C.Center	12.81	4.50
2018	39.0650	40.2840	C.Center	12.80	4.20

In this equation; *N* refers to the number of earthquakes, *M* refers to the size of earthquake, *a* and *b* refers to regression coefficients. The least squares method was used to find the coefficients a and b in the equation (Eq. (2) and

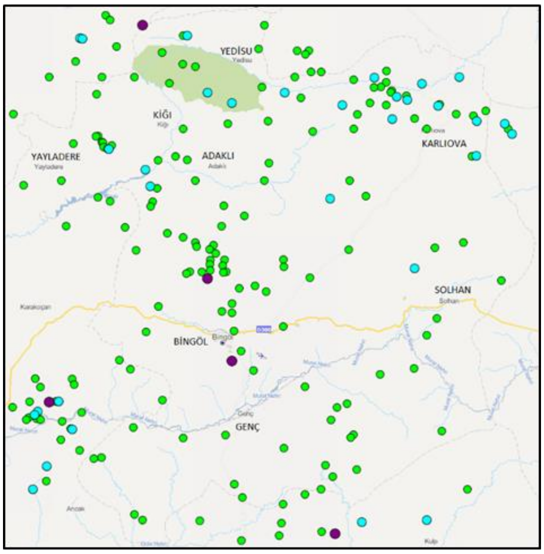

Fig. 6 From 1907 to 2018 occured earthquakes in Bingöl

Table 3 Relation between earthquake magnitudes and frequencies

Magnitude Ranges	$4 \leq M < 4.5$	$4.5 \leq M < 5$	$5 \leq M < 5.5$	$5.5 \leq M < 6$	$6 \leq M < 6.5$	$6.5 \leq M < 7$
Average Magnitude M (X_i)	4.25	4.75	5.25	5.75	6.25	6.75
Ni (Frequency)	73	20	6	0	1	1
$\sum Ni$ (Cumulative Frequency)	101	28	8	2	2	1
$\sum Ni/t$	0.9099	0.2523	0.0721	0.0180	0.0180	0.0090
Log $\sum Ni/t$ (Yi)	-0.0410	-0.5982	-1.1422	-1.7443	-1.7443	-2.0453

(3)). *a* in the equation; is the parameters of the area examined and the observation period, *b* is the parameters depending on the tectonic properties of the studied area (Kalyoncuoğlu and Ö zer 2005)

$$\text{Log N} = a + b.M \tag{1}$$

$$b=(\sum XiYi-[(\sum Xi\sum Yi)/m])/[(\sum Xi2)-[(\sum Xi)2/m]] \tag{2}$$

$$a=[\sum Yi/m]-b[\sum Xi/m] \tag{3}$$

The m value in Eqs. (2) and (3) is the number of earthquake magnitude ranges. The mean values for each magnitude range of $M \geq 4$ earthquakes were calculated. Then the cumulative numbers ($\sum Ni$) were found and the calculations in Table 3 were performed. Here, *t* refers to the duration of the earthquake.

When the values in the table are put in the formula, *a* and *b* values of the Gutenberg-Richter equation of Bingöl province were found to be 3.20 and -0.80 (Eq. (4)).

$$\text{Log N} = 3.20 - 0.80M \tag{4}$$

Thus, the relation of the magnitude-formation number was revealed (Fig. 7). There is an approximately linear relationship between the magnitude and frequencies (frequency of occurrence) of earthquakes since 1907, and

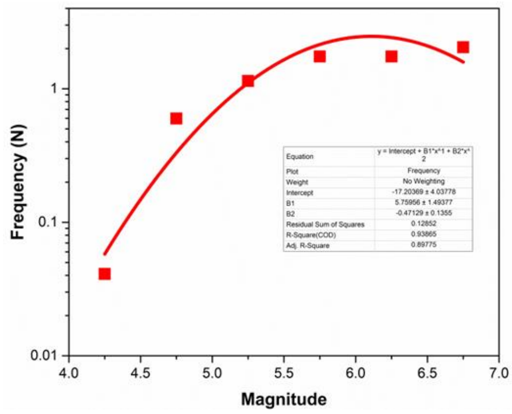

Fig. 7 Relationship between the magnitude and frequencies

Table 4 Earthquakes, occurrences and repetition periods in Bingol province

M	*N*(*M*)	Seismic Probability (%) *D* (Year)							Repetition Period (Year)
		10	20	30	40	50	75	100	
4	0.9685	100	100	100	100	100	100	100	1
4.5	0.3840	98	100	100	100	100	100	100	3
5	0.1522	78	95	99	100	100	100	100	7
5.5	0.0604	45	70	84	91	95	99	100	17
6	0.0239	21	38	51	62	70	83	91	42
6.5	0.0095	9	17	25	32	38	51	61	105
7	0.0038	4	7	11	14	17	25	31	266
7.5	0.0015	1	3	4	6	7	11	14	670

R^2=0.9373 shows that this relationship has a good correlation.

The Poisson probability model was used to obtain the probability that the ground motion parameter will be exceeded within a certain period of time. In the probabilistic seismic hazard analysis, the concept of Poisson probability model risk is calculated as in Eq. (5)

$$R(M)=1-e^{(-(N(M)D))} \tag{5}$$

In the equation; *D*, years (10, 20, 30, 40, 50, 75 and 100), *N*(*M*) refers to the number of magnitude of the Gutenberg-Richter correlation values. The repetition period is calculated by the following formula (Eq. (6))

$$Q=1/N(M) \tag{6}$$

Using Eq. (5) and (6), the probability values for the 10, 20, 30, 40, 50, 75 and 100 year certain time periods and the return period were calculated for the earthquake magnitudes (Table 4).

As seen in Fig. 8, the return period increases as the magnitude values increase. It is an exponential relationship between magnitude and return periods and this relationship can be expressed by the equation *y*=0.007e1.8334x. R^2=0.9995 indicates a strong correlation between magnitude and return periods. As a result of the statistical analysis of the earthquake data, the probability of occurrence of earthquakes of 6.5, 7.0 and 7.5 was calculated as 38%, 17% and 7%, respectively. According to the probabilistic earthquake hazard analysis, the magnitude of the project earthquake which is 10% exceeding in 50 years was found

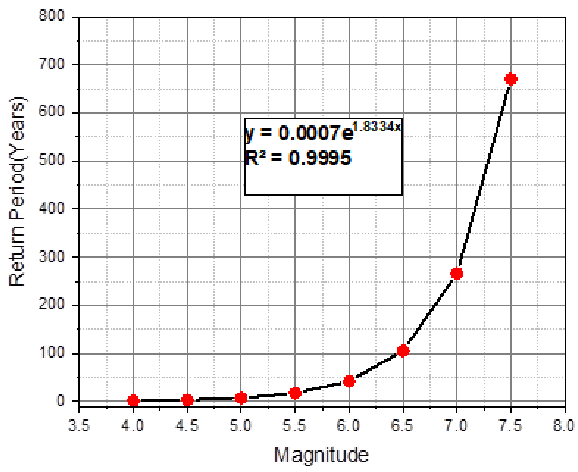

Fig. 8 Return period versus magnitude

Table 5 Average acceleration value obtained using various attenuation relationships

Various Attenuation Relationships	Acceleration (g)
Esteva (1970)	0.19
Davenport (1972)	0.56
Donovan (1973a)	0.37
Esteva and Villaverde (1973)	0.51
Donavan(1973b)	0.25
Donavan(1973c)	0.26
McGuier (1974)	0.34
Orphal and Lahoud (1974)	1.01
Shah *et al*. (1973)	0.46
Oliviera (1974)	0.19
Katayama	0.33
Esteva *et al*. (1978)	2.36
Joyner and Boore (1981)	1.21
Campbell (1981a)	0.20
Campbell (1981b)	0.20
Newmark and Roseblueth (1971)	0.34
Kanai (1966)	0.41
Esteva and Roseblueth (1964)	0.39
Fukishima *et al*. (1988)	0.31
Abrahamson and Litehiser (1989)	0.30
Campbel (1997)	0.48
Average	0.51

to be 7.4. In this study, a project area (Bingöl University) located in the city center of Bingöl was identified and the peak ground acceleration (PGA) value was calculated by using various earthquake attenuation relationships of this project area. At this stage, the average depth of the earthquakes *M*≥4 (23.53 km) occurred within the boundaries of the Bingöl province and the distance of the project area to the fault line (6 km), which constitutes the largest earthquake, was used. Away from the epicenter; short-term vibrations are damped more quickly than long-term ones. The depth of hypocenter is a measure of the depth of the earthquake. Where this depth is less than about 70 km shall be shallow, intermediate depth between 70-300 km and deeper earthquakes of more than 300 km. The hypocenter depth of the earthquakes in Turkey is usually between 10 and 30 km (Celep and Kumbasar 2004). The

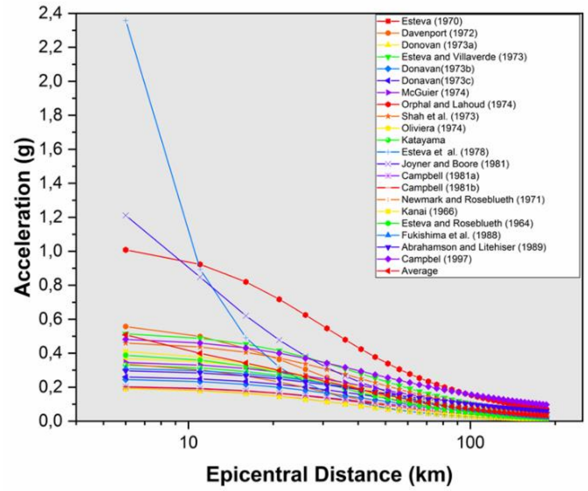

Fig. 9 The relationship between the acceleration-epicenter distances according to various attenuation relationships

earthquakes occured in Bingöl since 1907 have an average hypocenter depth of about 23 km therefore earthquakes in this region are shallow earthquakes. For this project area, where the earthquake has a magnitude of 10% exceeding in 50 years, various attenuation relationships have been used and the average ground acceleration has been determined with the above two parameters (Table 5).

Fig. 9 shows the acceleration of the acceleration relative to the epicenter distance according to various attenuation relationships. It has been determined that the acceleration of the acceleration values is increased by increasing the distance of the distance from the project area to 5 km each.

The average ground acceleration calculated according to

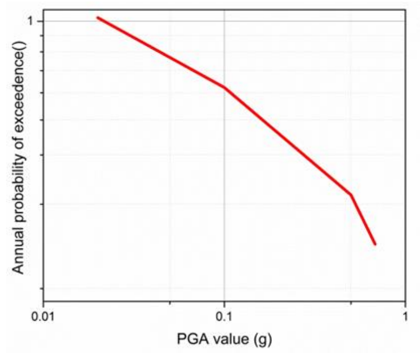

Fig. 10 The relation between annual probability of exceedance and PGA values

various attenuation relationships of the closest point to the fault was 0.51 g. Using Turkey seismic hazard map, Bingöl covering the province of peak ground acceleration for 20 points of the various seismic levels (PGA) and maximum ground velocity (PGV) values were obtained (Table 6). According to the results, the average PGA value was found to be 0.58 g the probability of %10 exceeding in 50 years. Fig. 10 plotted the relation between annual probability of exceedance and PGA values. When compared local ground motion and GMPE's average; pga values for probability of exceeding in 50 years %2, %10, %50, %68 obtained from the earthquake hazard map for the project area (38.899523, 40.484787-Bingol University, Faceulty of Engineering) is respectively 1,130 g, 0,65 g, 0,269 g and 0,178 g. As can be seen, the average of pga values from GMPE and pga values for exceeding 10% are close values. The reason for the difference is that; GMPE calculations take into account the earthquakes occurring, taking into account the earthquakes

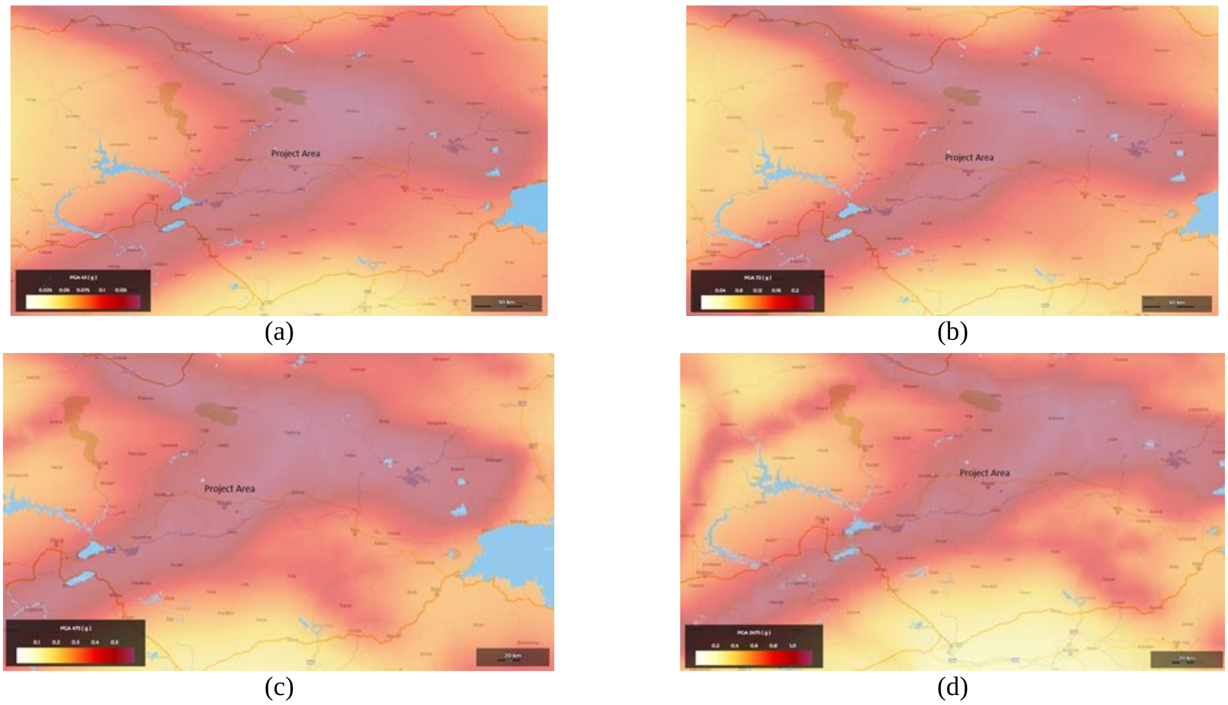

Fig. 11 Project area's hazard map for (a) 43 years return period (b) 72 years return period (c) 475 years return period (d) 2475 years return period

Table 6 Average PGA and PGV values of Bingol province

Latitude	Longitude	Peak Ground Acceleration (g)-PGA				Peak Ground Velocity (cm/s)-PGV			
		Probability of Exceeding in 50 Years				Probability of Exceeding in 50 Years			
		2%	10%	50%	68%	2%	10%	50%	68%
39.11	39.97	0.835	0.446	0.165	0.110	53.417	28.222	10.481	6.786
39.50	40.45	1.152	0.677	0.277	0.173	85.476	49.419	16.445	9.610
39.43	40.87	1.228	0.736	0.313	0.192	83.559	49.751	18.239	10.260
39.14	41.19	1.245	0.733	0.299	0.186	80.856	46.043	17.060	9.897
38.85	41.10	0.777	0.432	0.173	0.118	50.437	27.351	10.721	7.045
38.63	40.91	0.719	0.381	0.150	0.107	42.692	22.927	8.996	6.197
38.63	40.48	1.008	0.561	0.209	0.141	62.179	33.741	11.677	7.387
38.62	40.16	1.051	0.585	0.221	0.148	66.006	35.262	12.556	7.769
38.78	40.39	1.127	0.644	0.260	0.166	77.457	43.281	15.028	8.845
38.92	40.20	1.094	0.617	0.243	0.162	71.328	38.999	14.202	8.855
39.13	40.32	1.027	0.568	0.226	0.159	66.595	35.493	13.320	8.942
39.28	40.24	0.808	0.453	0.192	0.134	52.971	29.170	11.814	7.963
39.39	40.47	1.108	0.655	0.275	0.177	82.065	47.243	16.367	9.886
39.24	40.88	1.218	0.728	0.307	0.196	80.253	46.900	18.050	10.557
39.05	40.91	1.197	0.695	0.281	0.181	78.120	43.835	16.147	9.875
39.04	40.52	1.107	0.629	0.257	0.176	72.765	40.197	15.133	9.827
38.84	40.53	1.133	0.650	0.278	0.178	79.846	44.937	15.662	9.426
38.85	40.93	0.878	0.473	0.187	0.128	59.287	30.764	11.353	7.541
38.76	40.85	0.760	0.417	0.170	0.119	50.189	26.825	10.515	7.017
38.74	40.59	1.044	0.596	0.236	0.155	70.105	38.413	13.392	8.194
Average		1.03	0.58	0.24	0.16	68.28	37.94	13.86	8.59

occurring since 1907. The values obtained from the hazard map are the pga values calculated with earthquakes having a 475 year return period.

Received average pga values from hazard map for Bingol province is respectively; 0,16 g, 0,24 g, 0,58 g, 1,03 g. The average acceleration value obtained from 21 GMPEs was calculated as 0.51 g. Since the values obtained from the map are obtained from local earthquake stations, a detailed calculation result was not obtained. For this reason, it has larger values than the values obtained by attenuation relations. The same data sets were used for each GMPE to take into account the data after 1907. It is seen that the average of these values is close to the values obtained from the hazard map of 475 year return period. But among these, Joyner and Boore, Esteva and Orphal approaches are great because they take into account ground conditions and earthquake effects differently. Within the scope of this study, it is normal for different values to be generated for each motion equation. Because GMPEs used in the study are global equation sets. If local GMPEs were used, the values obtained would be similar and smaller. In addition, the hazard maps obtained from tdth.afad.gov.tr website are given for different return periods (Fig. 11), (Akkar and Cagnan 2010)

3. Conclusions

In this study, probabilistic seismic hazard analysis was performed by taking the earthquake records that occurred within the boundaries of Bingöl province. The seismicity of the region was obtained statistically by considering the earthquake records with a magnitude greater than 4 and the Gutenberg-Richter correlation. Magnitude-frequency relationship, seismic hazard and repetition periods were obtained for certain time periods (10, 20, 30, 40, 50, 75 and 100 years). The magnitude-frequency relationship was determined by considering the earthquakes occurred between 1900 and 2018 and the b values of the Gutenberg-Richter equation for Bingöl province were calculated as 3.20 and -0.80, respectively. According to the results of statistical analysis of earthquake data, the probability of occurrence of earthquakes of 6.5, 7.0 and 7.5 in a period of 50 years was calculated as 38%, 17% and 7%, respectively. These possibilities indicate that the seismicity of the region is high. The average hypocenter depth of the earthquakes in Bingol was approximately 23 km. This earthquake depth, which is classified as shallow earthquakes, indicates that destructive earthquakes may occur. Considering the project area determined within the scope of the study, the average peak acceleration value covering the provincial boundaries was determined as 0.51 g. This value is an indication that the earthquakes that may occur are large earthquakes with high periods. Moreover, it is seen that the peak acceleration value obtained for the Bingöl province from the earthquake hazard map is close to the peak acceleration value obtained by using the attenuation relationships. Due to the high seismicity of the region, many studies have been conducted about the tectonic properties of the region. These studies facilitate the seismic hazard analysis on the region. Large-scale earthquakes occurred throughout the history of the region necessitate these studies in order to predict the earthquakes expected in the future. The earthquake effect and related regulations should be taken into consideration during the construction of the city of Bingöl which is located in tectonically moving belts.

References

Akkar, S. and Cagnan, Z. (2010), "A local ground-motion predictive model for Turkey, and its comparison with other regional and global ground-motion models", *Bull. Seismol. Soc. Am.*, **100**(6), 2978-2995. https://doi.org/10.1785/0120090367.

Akkar, S., Boore, D.M. and Gulkan, P. (2005), "An evaluation of the strong ground motion recorded during the May 1, 2003 Bingol Turkey, earthquake", *J. Earthq. Eng.*, **9**(2), 173-197. https://doi.org/10.1080/13632460509350538.

Anbazhagan, P., Vinod, J.S. and Sitharam, T.G. (2009). "Probabilistic seismic hazard analysis for Bangalore", *Nat. Hazard.*, **48**(2), 145-166. https://doi.org/10.1007/s11069-008-9253-3.

Andric, J.M. and Lu, D.G. (2017), "Fuzzy probabilistic seismic hazard analysis with applications to Kunming city, China", *Nat. Hazard.*, **89**(3), 1031-1057. https://doi.org/10.1007/s11069-017-3007-z.

Ashadi, A.L., Harmoko, U., Yuliyanto, G. and Kaka, S.I. (2015), "Probabilistic seismic-hazard analysis for central Java Province, Indonesia", *Bull. Seismol. Soc. Am.*, **105**(3), 1711-1720. https://doi.org/10.1785/0120140277.

Ayele, A. (2017), "Probabilistic seismic hazard analysis (PSHA) for Ethiopia and the neighboring region", *J. Afr. Earth Sci.*, **134**, 257-264. https://doi.org/10.1016/j.jafrearsci.2017.06.016.

Bwambale, B., Bagampadde, U., Gidudu, A. and Martini, F. (2015), "Seismic hazard analysis for the Albertine Region, Uganda - a probabilistic approach", *S. Afr. J. Geol.*, **118**(4), 411-424. https://doi.org/10.2113/gssajg.118.4.411.

Ceken, U., Beyhan, G. and Selim, H.H. (2014), "City of Bingol in May 2003: Assessment of strong ground motion records", *J. Earth Syst. Sci.*, **123**(2), 381-394. https://doi.org/10.1007/s12040-013-0394-8.

Celep, Z. and Kumbasar, N. (2004), "Deprem muhendisligine giris ve depreme dayanikli yapi tasarimi", Beta Dagitim, Istanbul.

Celep, Z., Erken, A., Taskin, B. and Ilki, A. (2011), "Failures of masonry and concrete buildings during the March 8, 2010 Kovancilar and Palu (Elazig) earthquakes in Turkey", *Eng. Fail. Anal.*, **18**(3), 868-889. https://doi.org/10.1016/j.engfailanal.2010.11.001.

De, Almeida, A.A.D., Assumpcao, M., Bommer, J.J., Drouet, S., Riccomini, C. and Prates, C.L.M. (2019), "Probabilistic seismic hazard analysis for a nuclear power plant site in southeast Brazil", *J. Seismol.*, **23**(1), 1-23. https://doi.org/10.1007/s10950-018-9755-8.

Dogangun, A. (2004), "Performance of reinforced concrete buildings during the May 1, 2003 Bingol earthquake in Turkey", *Eng. Struct.*, **26**(6), 841-856. https://doi.org/10.1016/j.engstruct.2004.02.005.

Görgün, B. and Ural, N. (2018), "Determination of seismicity of Bilecik City center", *El-Cezeri J. Sci. Eng.*, **5**(2), 394-402. (in Turkish)

Gutenberg, B. and Richter, C.F. (1944), "Frequency of earthquakes in California", *Bull. Seismol. Soc. Am.*, **34**(4), 185-188.

Harman, E.K. (2016), "Probabilistic seismic hazard analysis for the city of Sakarya", *Sakarya Uni. J. Sci.*, **20**(1), 23-31. (in Turkish)

Ince, Y. and Kurnaz, T.F. (2018), "Probabilistic seismic hazard analysis of Kahramanmaras Province, Turkey", *Arab. J. Geosci.*, **11**(5), 97. https://doi.org/10.1007/s12517-018-3434-5.

Işık, E., Aydın, M.C., Bakış, A. and Özlük, M.H. (2012), "The faults near bitlisand seismicity of the region", *EU. J. Sci.*, **1**(2), 153-169.

Kalyoncuoğlu, Ü.Y. and Özer, M.F. "Seismicity of Turkey, tectonics and high-risk areas a new approach, in Turkish", *Proc., Earth Symposium*.

Karaca, H. (2017), "Obtaining seismic hazard map and response spectrum curve by using the latest data andprobabilistic seismic hazard analysis", *J. Facult. Eng. Arch. Gazi Uni.*, **32**(1), 265-273. (in Turkish)

Kartal, R.F., Beyhan, G. and Keskinsezer, A. (2014), "Seismic hazard analysis of Sinop province, Turkey using probabilistic and statistical methods", *J. Earth Syst. Sci.*, **123**(3), 565-579. https://doi.org/10.1007/s12040-014-0424-1.

Kartal, R.F., Beyhan, G., Keskinsezer, A. and Kadirioglu, F.T. (2014), "Seismic hazard analysis of Mersin Province, Turkey using probabilistic and statistical methods", *Arab. J. Geosci.*, **7**(10), 4443-4459. https://doi.org/10.1007/s12517-013-1104-1.

Kayabalı, K. (1995), "Seismic hazard analysis; theory and application", *J. Geo. Eng.*, **46**(1), 28-43.

Mahmoudi, M., Shayanfar, M., Barkhordari, M.A. and Jahani, E. (2016), "New fuzzy method in choosing ground motion prediction equation (GMPE) in probabilistic seismic hazard analysis", *Earthq. Struct.*, **10**(2), 389-408. https://doi.org/10.12989/eas.2016.10.2.389.

Mahsuli, M., Rahimi, H. and Bakhshi, A. (2019), "Probabilistic seismic hazard analysis of Iran using reliability methods", *Bull. Earthq. Eng*, **17**(3), 1117-1143. https://doi.org/10.1007/s10518-018-0498-2.

Mantyniemi, P., Marza, V.I., Kijko, A. and Retief, P. (2003), "A new probabilistic seismic hazard analysis for the Vrancea (Romania) seismogenic zone", *Nat. Hazard.*, **29**(3), 371-385. https://doi.org/10.1023/A:1024787621646.

Milkereit, C., Grosser, H., Wang, R.J., Wetzel, H.U., Woith, H., Karakisa, S., Zunbul, S. and Zschau, J. (2004), "Implications of the 2003 Bingol earthquake for the interaction between the north and east anatolian faults", *Bull. Seism. Soc. Am.*, **94**(6), 2400-2406. https://doi.org/10.1785/0120030194.

Mulargia, F., Stark, P.B. and Geller, R.J. (2017), "Why is probabilistic seismic hazard analysis (PSHA) still used?", *Phys. Earth Planet Inter.*, **264**, 63-75. https://doi.org/10.1016/j.pepi.2016.12.002.

Naidu, G.D., Selvan, S., Tripathy, G.R. and Pattanur, L.R. (2018), "Probabilistic seismic hazard analysis for Jabalpur area, Madhya Pradesh, India", *J. Ind. Geophys. Uni.*, **22**(4), 389-398.

P.M.D.E.M. Authority (2019), Turkey Earthquake Hazard Maps.

Pailoplee, S. and Charusiri, P. (2016), "Seismic hazards in Thailand: a compilation and updated probabilistic analysis", *Earth Planet Space*, **68**(1), 98. https://doi.org/10.1186/s40623-016-0465-6.

Rangin, C., Bader, A.G., Pascal, G., Ecevitoglu, B. and Gorur, N. (2002), "Deep structure of the Mid Black Sea High (offshore Turkey) imaged by multi-channel seismic survey (BLACKSIS cruise)", *Marin. Geol.*, **182**(3-4), 265-278. https://doi.org/10.1016/S0025-3227(01)00236-5.

Rehman, S.U., Khalid, M., Ali, A. and Abd El-Aal, A.K. (2013), "Deterministic and probabilistic seismic hazard analysis for Gwadar City, Pakistan", *Arab. J. Geosci.*, **6**(9), 3481-3492. https://doi.org/10.1007/s12517-012-0635-1.

Sayin, E., Yon, B., Calayir, Y. and Gor, M. (2014), "Construction failures of masonry and adobe buildings during the 2011 Van earthquakes in Turkey", *Struct. Eng. Mech.*, **51**(3), 503-518. https://doi.org/10.12989/sem.2014.51.3.503.

Sayin, E., Yon, B., Calayir, Y. and Karaton, M. (2013), "Failures of masonry and adobe buildings during the June 23, 2011 Maden-(Elazig) earthquake in Turkey", *Eng. Fail. Anal.*, **34**, 779-791. https://doi.org/10.1016/j.engfailanal.2012.10.016.

Sezer, L.I. (2008), "Seismicity in the Karliova (Bingol) Region", *Aegean Geogr. J.*, **17**(1-2), 35-50.

Sil, A., Sitharam, T.G. and Kolathayar, S. (2013), "Probabilistic seismic hazard analysis of Tripura and Mizoram states", *Nat. Hazard.*, **68**(2), 1089-1108. https://doi.org/10.1007/s11069-013-0678-y.

Sokolov, V., Zahran, H.M., Youssef, S.E., El-Hadidy, M. and

Alraddadi, W.W. (2017), "Probabilistic seismic hazard assessment for Saudi Arabia using spatially smoothed seismicity and analysis of hazard uncertainty", *Bull. Earthq. Eng*., **15**(7), 2695-2735. https://doi.org/10.1007/s10518-016-0075-5.

Ulusay, R. and Aydan, O. (2005), "Characteristics and geo-engineering aspects of the 2003 Bingol (Turkey) earthquake", *J. Geodyn*., **40**(2-3), 334-346. https://doi.org/10.1016/j.jog.2005.07.018.

Yücemen, M.S. (2011), "Probabilistic seismic hazard assessment: general overview and considerations in statistical modeling", *1st Turkey Earthquake Engineering and Seismology Confenerence*, Ankara, Turkey, October.

AT