# Frequency analysis of annual maximum earthquakes for Aşkale, Erzurum (Turkey) province

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*Abstract:* - The aim of this study is to investigate the seismicity of Aşkale County which is located 45 km from Erzurum city in eastern Turkey, a statistical frequency analysis is applied for the annual maximum earthquake magnitudes, occurred between 1900 – 2014 years in the seismotectonic zones around Aşkale County, using various probability distribution models (GEV, Gumbel, Gamma and Pearson III). The goodness-of-fit test is applied to these four distributions and the best fitted distribution is chosen as the Gamma distribution for this data set that is taken from the internet page published by Kandilli Observatory. Probable earthquake magnitudes for the return periods (T) 50 years and 100 years are also investigated for the 95% significance level by using the Gamma distribution. For an economic period of 50 years, the average return periods of critical magnitudes computed for the Risks of 10%, 5% 1% are 297, 611, 3115 years, respectively. The tectonic structure and seismic properties of Aşkale province are also given in the study.

*Key-Words:* - Frequency analysis; Earthquake; Seismic Risk; Aşkale; Goodness-of-fit test; The Northeast Anatolian Fault

## 1 Introduction

An earthquake is defined as both a sudden slip on a fault, and the resulting ground shaking and radiated seismic energy caused by the slip, or by underground activity, or other sudden stress changes in the earth. Earthquakes can last from a few seconds to over five minutes; they may also occur as a series of tremors over a period of several days. The actual movement of the ground in an earthquake is seldom the direct cause of injury or death. Casualties may result from falling objects and debris, because the seismic shocks shake, damage, or demolish buildings and other structures. Disruption of communications, electrical power supplies and gas, sewer and water lines should also be expected. Earthquakes may trigger fires, dam failures, landslides or releases of hazardous material, compounding their disastrous effects.

The term "earthquake risk" is used loosely in a variety of senses, (i) The geophysical risk (or earthquake hazard) is the expected rate of occurrence (number of events per unit time) within a prescribed region and over a certain magnitude level, (ii) The engineering risk is the expected rate of occurrence of exceedances of a specified level of ground motion (measured either in terms of Mercalli intensity or ground acceleration) at a particular site or within a prescribed region, and (iii) The economic risk is the expected losses, per unit time, from earthquakes affecting a particular city or other specified region [1]. In this study, the term "earthquake risk" is used as the general term for a probability or expected rate of occurrence of a damaging event.

The most important parameters to assess the earthquake risk for a region are occurrence frequency, epicentre, depth and magnitude of the seismic events, focal mechanisms, geological and tectonic parameters of the region. There are two approach used in seismic risk assessment: deterministic and probabilistic seismic risk analyses, respectively. In deterministic seismic risk analysis, it is firstly determined the seismic faults which could affect the region and occurred earthquakes in the past on this faults. Secondly, maximum ground acceleration which would be produced by the faults around the region is computed by choosing optimum correlation of regression corresponds the characteristics of the region [2]. On the other hand, probabilistic seismic risk analysis was developed by Cornell (1968) [3] by taken into account the uncertainty in geometries of seismic sources, in geological and tectonic parameters, in damping mechanisms and in magnitudes of expected earthquakes. The probabilistic seismic risk assessment consists of five stages [4]: (i) identify all earthquake sources capable of producing damaging ground motions, (ii) characterize the distribution of earthquake magnitudes (the rates at which earthquakes of various magnitudes are expected to occur), (iii) characterize the distribution of source-to-site distances associated with potential earthquakes, (iv) predict the resulting distribution of ground motion intensity as a function of earthquake magnitude, distance, etc. and (v) combine uncertainties in earthquake size, location and ground motion intensity, using a calculation known as the total probability theorem (Fig. 1).

In this study, to investigate the seismicity of Aşkale County which is located 45 km away from Erzurum city in eastern Turkey, a statistical frequency analysis is applied for the annual maximum earthquake magnitudes, occurred between 1900 – 2014 years in the seismotectonic zones around Aşkale County, using various probability distribution models (GEV, Gumbel, Gamma and Pearson III). An area of 100 km radius to Aşkale has been taken into account. The earthquake data are obtained from Kandilli Observatory and Earthquake Research Institute. The goodness-of-fit test is applied to these four distributions and the best fitted distribution is determined.

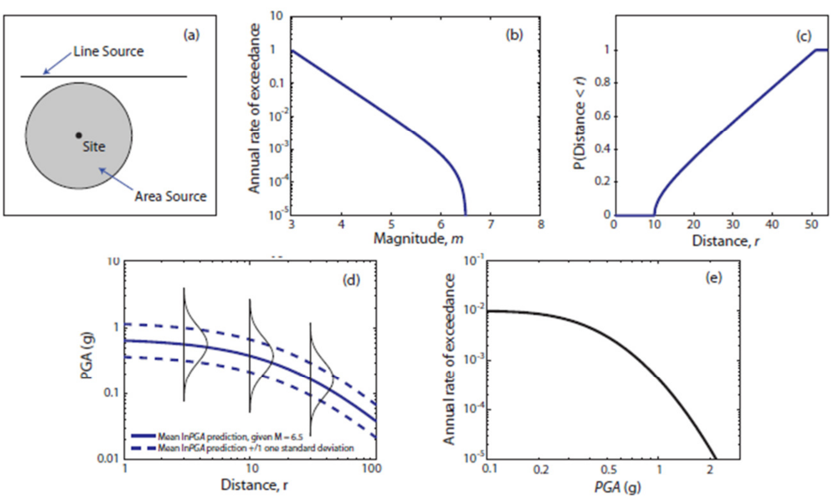


**Figure 1.** Schematic illustration of the basic five steps in probabilistic seismic hazard analysis (a) identify earthquake sources, (b) characterize the distribution of earthquake magnitudes from each source, (c) characterize the distribution of source-to-site distances from each source, (d) predict the resulting distribution of ground motion intensity, (e) combine information from parts a-d to compute the annual rate of exceeding a given ground motion intensity [4].

## 2 Seismological Aspects

The seismicity of Aşkale (Erzurum) is mainly related with the tectonic deformation of the region controlled by the collision of the Arabian and Eurasian Plates. The Anatolian block is surrounded by the North Anatolian and East Anatolian faults (Figure 2). The Northeast Anatolian Fault, one of the most important subsections of the East Anatolian province, is located between Karlıova triple junction and Armenia. In the region, there are a number of parallel faults, i.e. the Kelkit Fault, Akdağ Fault, Aşkale Fault, Dumlu Fault and Çobandede Fault (Figure 3) [6].

There have been no historical or instrumental records of powerful earthquakes in the vicinity of Aşkale Fault, so Aşkale-Çayırlı has been considered a seismic gap, and could produce powerful earthquakes [6]. On the other hands, Erzurum is located on one of the most important fault zones of Eastern Anatolia. A large part of Erzurum province is in the second degree earthquake zone (Figure 4). However, many active faults produce destructive earthquakes. For example the Erzurum Fault, is left strike-slip fault, is about 50 km east of the Aşkale Fault, approximately 80 km long, and could produce an earthquake with a magnitude greater than 7 on the Richter scale. Besides, there are a lot of active faults over several 10 km long located on the NE of the Erzurum Fault in Dumlu-Tortum and Horasan-Narman provinces. In addition of these faults, a left strike-slip fault zone exists between Aşkale-İspir provinces. The Erzurum province experienced destructive earthquake according to both instrumental and historical records, because of the many active faults. For example, in the last century, in the year 1924, an earthquake of magnitude 6.8 on the Richter scale hit the Pasinler County, causing 310 deaths and 4300 buildings were heavily damaged. In the Erzurum-Kars earthquake (1983),

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the magnitude is 6.8 on the Richter scale and caused 1155 deaths and 3241 buildings were heavily damaged or collapsed [6, 8]. Another example (2004) is Aşkale earthquakes of magnitudes 5.1 and 5.3 on the Richter scale. These earthquakes hit the Aşkale province within three days and caused 10 deaths, 19 injuries and 1212 traditional masonry buildings were heavily damaged [9, 10]. It is known that, according to the historical records, in the years between A.D. 1400 and A.D. 1890, many destructive earthquakes hit the Erzurum province. For example, in the year 1859, a very destructive earthquake hit the Erzurum province and caused about 15000 deaths [8].

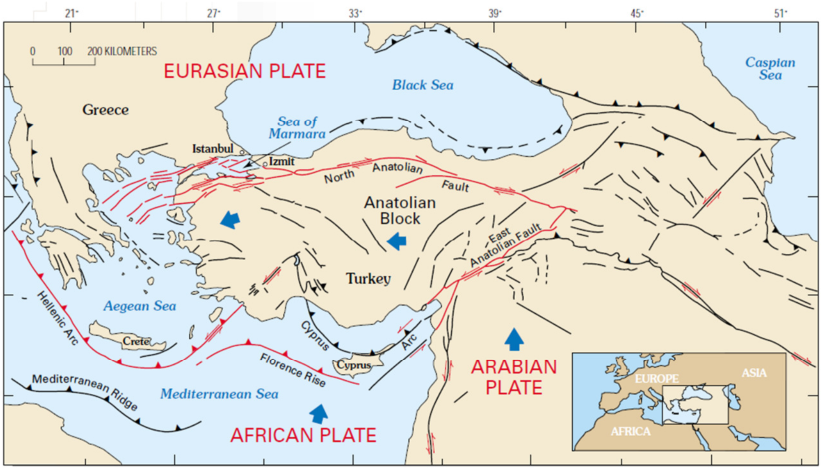


**Figure 2.** Simplified Tectonic Map of Turkey [5]

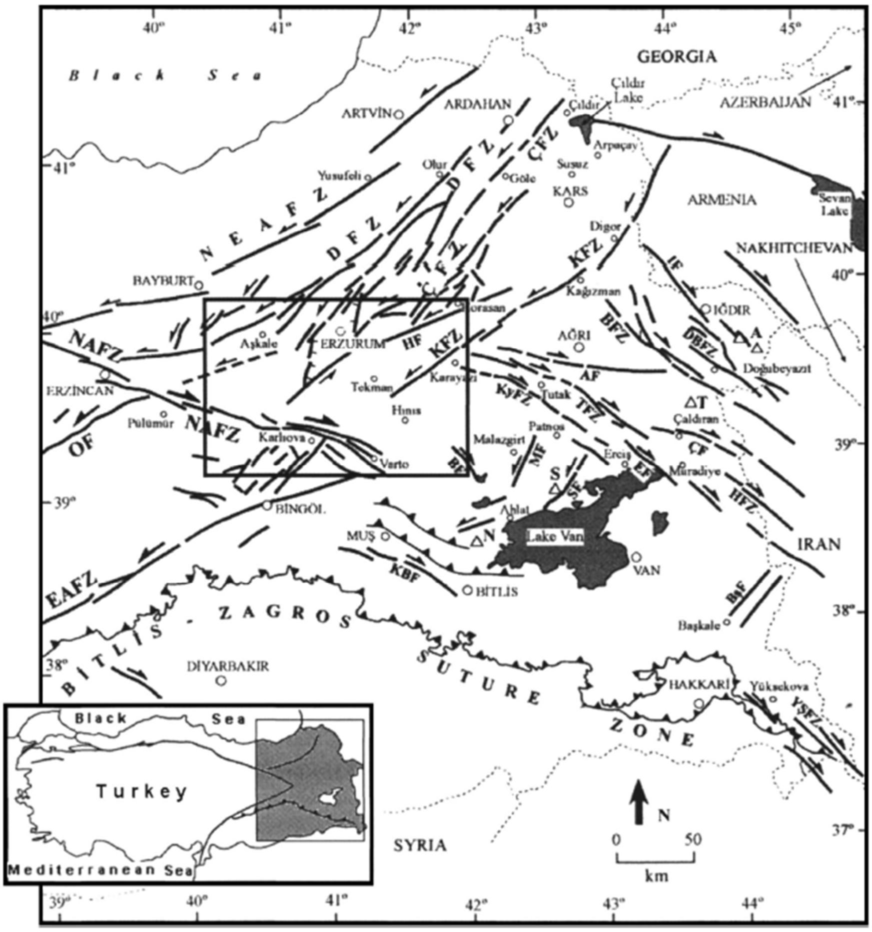


**Figure 3.** Major structural elements of Eastern Anatolia (NAFZ—North Anatolian Fault Zone; NEAFZ—Northeast Anatolian Fault Zone; DFZ—Dumlu Fault Zone; ÇFZ—Çobandede Fault Zone; HF—Horasan Fault; KFZ—Kağızman Fault Zone; and EAFZ—East Anatolian Fault Zone) [6]

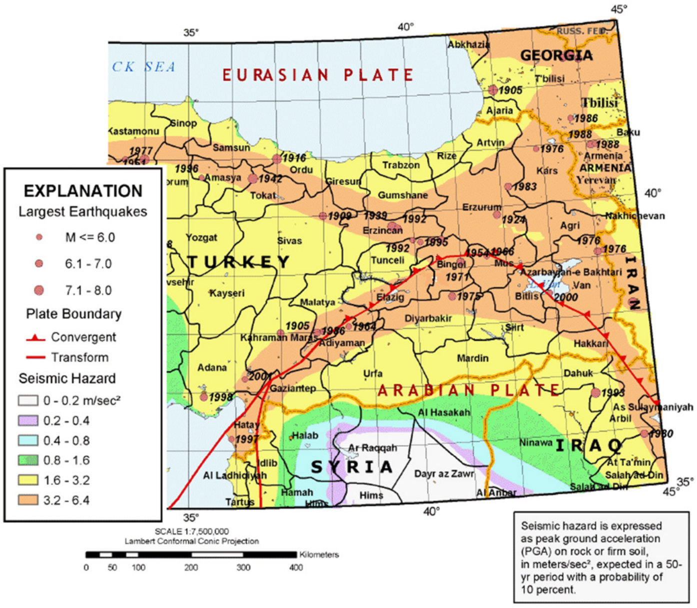


**Figure 4.** Seismic hazard settings of Eastern Turkey (modified from [7])

## 3 Statistical distributions

All the parameters are estimated by the method of maximum likelihood given by the Weibull formula in all calculation as [11]

$$F = k/(n+1) \tag{1}$$

All statistical distributions and their functions that are analyzed in this study are shown in Table 1.

## 4 Goodness-of-fit test

It is necessary to consider a test to determine if a sample record has a specified theoretical distribution. The aim of the test is to decide how good a fit is between the frequency of occurrence observed in a sample and the expected frequencies obtained from the hypothesized distribution. A goodness-of-fit test between observed and expected frequencies is based on the Chi-square quantity, which is defined as,

$$\chi^2 = \sum_{i=1}^{k} (o_i - e_i)^2 / e_i \tag{2}$$

where $\chi^2$ is a random variable whose sampling distribution is approximated very closely by the Chi-square distribution. The symbols $o_i$ and $e_i$ represent the observed and expected frequencies, respectively, for the $i$-th class interval in the histogram.

**Table 1.** Statistical distributions and their functions

| Statistical Distributions | Functions |
|---|---|
| Generalized Extreme Value ( GEV ) [12] | $f(x)=\frac{1}{\alpha}.\left[1-\frac{k}{\alpha}(x-u)\right]^{1/k-1}.\exp\left\{-\left[1-\frac{k}{\alpha}(x-u)\right]^{1/k}\right\}$ |
| Gumbel [13, 14] | $f(x)=\frac{1}{\alpha}\exp\left[\left(-\frac{x-u}{\alpha}\right)-\exp\left(-\frac{x-u}{\alpha}\right)\right]$ |
| Two-Parameter Gamma | $f(x)=\frac{\alpha^{\lambda}}{\Gamma(\lambda)}x^{\lambda-1}e^{-\alpha x}$ |
| The Pearson III | $f(x)=\frac{\alpha^{\lambda}}{\Gamma(\lambda)}(x-m)^{\lambda-1}e^{-\alpha(x-m)}$ |

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If the observed frequencies are close to the corresponding expected frequencies, the $\chi^2$ value will be small, indicating a good fit; otherwise, it is a poor fit. A good fit leads to the acceptance of $H_0$ (null hypothesis), whereas a poor fit leads to its rejection. The critical region will, therefore, fall in the right tail of the chi-square distribution. For a level of significance equal to α, the critical value $\chi^2_\alpha$ is found from readily available Chi-square tables and $\chi^2 > \chi^2_\alpha$ constitutes the critical region [15].

The decision criterion described here should not be used unless each of the expected frequencies is at least equal to 5. Herein, α (the significance level) is chosen as 0.05. These statistical distributions for earthquake magnitudes for Aşkale County are performed by the goodness-of-fit $\chi^2$ test. The Chi-square values and probability values of the statistical distributions are compared (Table 2). One can then determine the best fitting distribution earthquake magnitudes by observing which distribution yields the smallest Chi-square value. The results show GEV and Pearson Type III distributions are rejected for the significance level 95%. The Gumbel and Gamma distributions are accepted but the best fitted distribution is the Gamma distribution because its $\chi^2$ value is less and the probability value (p) is higher than the Gumbel distribution values. The estimated statistical parameters of the analyzed distributions are shown in Table 3.

By using the Gamma distribution to the annual maximum earthquake magnitudes for Aşkale, the probable earthquake magnitudes for the return periods (T) 50 years and 100 years are also investigated for the 95% significance level. The possible earthquake magnitude is 6.33 for T = 50 years and 6.51 for T = 100 years.

**Table 2.** Goodness of fit tests to all statistical distributions for earthquake magnitudes

| Distribution | Chi-square | p |
|---|---|---|
| GEV | 17.77 | 0.0130 |
| GUMBEL | 9.41 | 0.3090 |
| GAMMA | 6.93 | 0.5442 |
| PEARSON III | 17.77 | 0.0130 |

**Table 3.** Estimated statistical parameters of the analyzed statistical distributions

| Statistical Distributions | α | m | k | u | λ |
|---|---|---|---|---|---|
| GEV | 0.546016 | - | 0.135698 | 4.76916 | - |
| GUMBEL | 0.53879 | - | - | 4.72741 | |
| GAMMA | 14.0497 | - | - | - | 70.5057 |
| PEARSON III | 6.45306 | 2.66251 | - | - | 15.2021 |

In a definite geographical area, too small earthquakes having immeasurable magnitudes may happen within a whole year's period. The relationship between the earthquake magnitude and the average return period and hence the probabilities of non-exceedance and of exceedence for latter case are [16]:

$$P_{nex} = P(0 < x \le x_T) = 1 - 1/T = F(x = x_T) = \int_0^{x_T} f(x)dx \qquad (3)$$

and,

$$P_{ex} = P(x_T < x < +\infty) = 1/T = 1 - F(x = x_T) = 1 - \int_0^{x_T} f(x)dx \qquad (4)$$

where, $P_{nex}$ is the non-exceedance probability of, $P_{ex}$ is the exceedance probability of, and $T$ is the average return period of the magnitude of earthquake intensity equaling $x_T$, *f(x)* is the probability density function, and *F(x)* is the cumulative distribution function of *x*, as *x* denotes the random variable of annual maximum earthquake. $x_T$ in Eqs. (3) and (4) is the critical earthquake magnitude, and any earthquake of magnitude greater than $x_T$ will cause the collapse of the structure, and hence, $P_{ex}$ in Eq. (4) is the probability of failure of the building in any single year due to earthquake.

Risk is analytically described as,

$$\text{Risk} = 1-(1-1/T)^N \tag{5}$$

where, *T* is the average return period in years and *N* is the economic life of the building in years. This equation relates the average return period to the economic life and to the Risk, which are determined according to type and usage of the building as specified in the pertinent codes. The value of $x_T$, magnitude of the critical earthquake, is calculated by a suitable probability distribution versus *T*.

Eq. (5) assumes that there are no zero-earthquake years in that geographical area. Yet, in elsewhere in the world, there are some specific geographical areas in which no noticeable earthquakes occur within some one-year periods. In this case, the series of recorded annual maximum earthquakes consist of two pieces, one: zero- earthquake years, and the other: greater than zero- earthquake years. Eq. (5) is not valid for such series, and the probability of non-exceedence in any one year for those series comprising zero- earthquake years is defined as

$$P_{nex} = P(x=0) + P(0 < x \le x_T) = P_0 + P(0 < x \le x_T) \tag{6}$$

The term $P_0$ appearing in this equation denotes the probability of the earthquake magnitude equaling zero in any one year, and its value by the general probability rule is defined by

$$P_0 = \lim_{n\to\infty}(m/n) \approx m/n \tag{7}$$

where, *m* is the number of no-earthquake years in a total period of *n* years, and Eq. (7) approximates the probability by the relative frequency assuming that n is so large as to be close to infinity.

When the Risk and the economic life, *N*, of a building are specified according to some regulations or codes, then the average return period of the critical magnitude of the design earthquake can be computed by

$$T = 1/\left\{1-\left[\frac{(1-Risk)^{(1/N)}-P_0}{1-P_0}\right]\right\} \tag{8}$$

The one with the greatest magnitude of the earthquakes that in any one-year period is selected and the others are discarded. Sample series of 71 elements of annual maximum magnitude earthquakes for 115-year span between 1900 and 2014 are hence obtained. In some years of a total 43 years there is no measurable earthquakes took place. Therefore, the probability of no- earthquakes in any one year by Eq. (7) is: $P_0 \approx 43/115 = 0.3739$.

For an economic period of 50 years, which is common for most buildings, and with a probability of zero- earthquake years assumed to be $P_0 \approx 0.3739$, the average return periods of critical magnitudes computed by Eq. (8) for the Risks of 10%, 5% 1% are 297, 611, 3115 years, respectively.

# 4 Conclusion

In this study, the statistical frequency analyses are applied to the recorded annual maximum earthquake magnitudes for Aşkale (Erzurum) since 1900. The probability distributions of GEV, Gumbel, Gamma and Pearson type III are used as candidate distributions, by methods of maximum likelihood. The goodness-of-fit test of Chi-square is help in deciding on the best-fit distribution in the 95% significance level. The results showed that the Gumbel and Gamma distributions can be accepted as fitted distributions but the best fit-distribution is the Gamma distribution due to Chi-square value and the probability value. The possible earthquake magnitude is 6.33 for T = 50 years and 6.51 for T = 100 years are also another results of analysis.

For an economic period of 50 years, the average return periods of critical magnitudes computed for the Risks of 10%, 5% 1% are 297, 611, 3115 years, respectively.

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