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Relationships Between Fundamental Seismic Hazard Parameters for the Different Source Regions in Turkey

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Abstract. Turkey has been divided into eight different seismic regions taking into consideration the tectonic environments and epicenters of the earthquakes to examine relationships of the modal values (a/b), the expected maximum magnitudes (M_{max}) and the maximum intensities (I_{max}). For this purpose, the earthquakes for the time period 1900–1992 from the Global Hypocenter Data Base CD-ROM prepared by USGS, and for the time period 1993–2001 from the PDE data and IRIS data are used. Concerning the relationships developed between different magnitude scales and between surface wave magnitudes (M_S) and intensity for different source regions in Turkey, we have constructed a uniform catalog of M_S. We have estimated the values of M_{max} and I_{max} using the Gumbel III asymptotic distribution. Highest a-values are observed in the Aegean region and the lowest b-values are estimated for the North Anatolian Fault. Maximum values of a/b, M_{max} and I_{max} are related to the eastern and western part of the North Anatolian Fault and the Aegean Arc. The lowest values of all parameters are observed near the Mid Anatolian Fault system. Linear relationships have been calculated between a/b, M_{max} and I_{max} using orthogonal regression. If one of the three parameters is computed, two other parameters can be calculated empirically using these linear relationships. Hazard maps of M_{max} and I_{max} values are produced using these relationships for a grid of equally spaced points at 1°. It is observed that the maps produced empirically may be used as a measure of seismic hazard in Turkey.

Key words: Gutenberg–Richter relationship, intensity, magnitude, modal values, seismic hazard

1. Introduction

Several researchers have used different statistical models to estimate the size of earthquake occurrences such as expected magnitude, intensity, ground acceleration, velocity or displacement. The processes in these models may be separated into two categories; (a) "whole process" methods

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using whole data set such as Gutenberg–Richter relationship, and (b) ''part process'' methods using part of data set such as extreme values.

The evaluation of these parameters have been frequently used in statistical calculation of seismicity since Gutenberg and Richter (1944) estimated the parameters a and b. The parameters a and b for different source regions and different time interval were determined by several authors (see e.g. Miyamura, 1962; Båth, 1981; Bender, 1983; Tsapanos and Papazachos, 1998; Yılmaztürk *et al.*, 1999; Olsson, 1999). Recently, Yılmaztürk *et al.* (1999) and Bayrak *et al.* (2002) showed that distribution of modal values (a/b) provide detailed images of the local areas demonstrated by high and low seismic zones in Turkey and the world.

Models of the second category may be more appropriate for earthquake catalogs because they do not require completing the records of earthquake occurrence. Nordquist (1945) showed that ''theory of extreme values'' is applicable to earthquake magnitude data and Gumbel (1958) developed extreme value statistics. The theory of extremes provides a convenient method to obtain occurrence of natural events and has been used in seismic hazard studies (e.g. Epstein and Lomnitz, 1966; Yegulalp and Kuo, 1974; Lilwall, 1976; Burton, 1979; Makropoulos and Burton, 1986).

Turkey has complex plate tectonics. There are a number of microplates that have seismically and tectonically active boundaries experienced with destructive earthquakes. Because of this high activity, several researchers studied seismicity of Turkey and formed the maps of seismic risk or seismic hazard for different time period (e.g. Dewey, 1976; Yarar *et al.*, 1980; Burton *et al.*, 1984; Erdik *et al.*, 1985; Yılmaztürk *et al.*, 1999).

The aim of this study is to determine reliable relationships between different seismic hazard parameters to show that these parameters are related to each other. Taking into account the tectonics and geographical distribution of the earthquakes, Turkey has been divided into eight different source regions to calculate the modal values, the maximum magnitudes (M_{max}), the intensities (I_{max}) and corresponding hazard maps.

2. Tectonics

The tectonic activity of Turkey and surrounding area depends on relative motions between the African, the Aegean, the Arabian, the Anatolian, the Black Sea and the Eurasian plates (Kasapoğlu and Toksöz, 1983). The most important tectonic environments (the Aegean Arc, the West Anatolian Graben Complexes (WAGC), the North Anatolian Fault (NAF) and the East Anatolian Fault (EAF), the Bitlis-Zagros thrust zone (BZTZ) and the Caucasus) are shown in Figure 1. The Aegean Arc is formed as the African plate is subducted beneath the Aegean plate to the North (Papazachos *et al.*, 1991). In the West Anatolia the graben complexes have

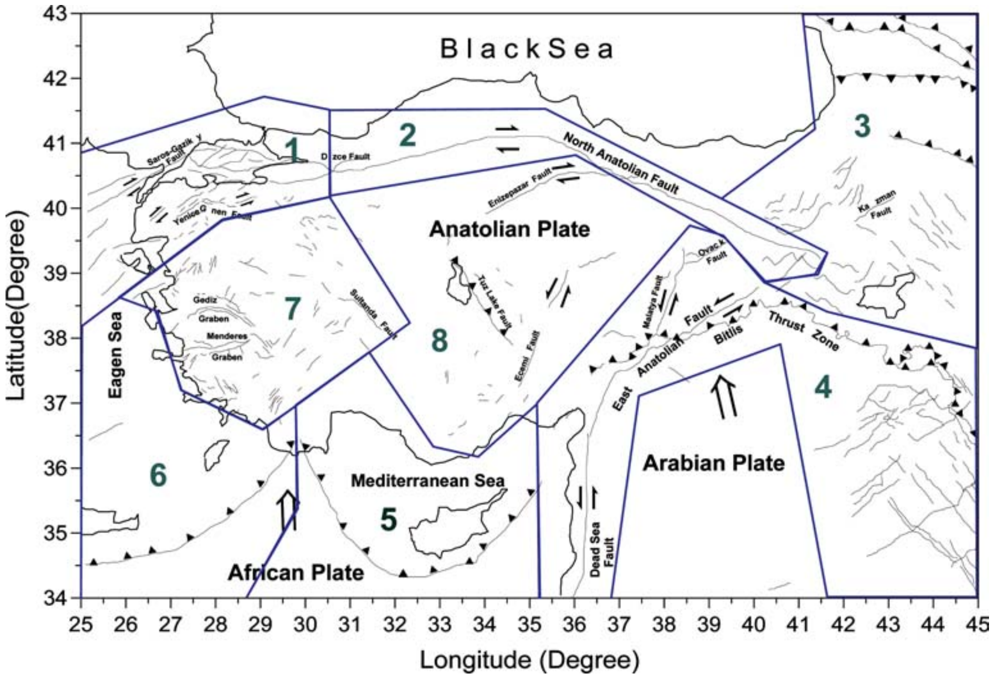

Figure 1. Tectonic map and the different source regions in Turkey, taking into account in this study. The tectonic structures formed by Mineral Research and Exploration of Turkey (MTA) were modified.

occurred in the direction of W–E since there has been an extension in the N–S trending. The Arabian plate is moving in the north–northwest direction relatively to the Eurasian plate. This motion has resulted in continental collision along the Bitlis-Zagros fold and the thrust belt and causes high topography in eastern Turkey and the Caucasus (McKenzie, 1970). As a result of compression in the east Anatolia, the Anatolian plate moves to the west and the north Anatolian plate to the east. The NAF and EAF settled down in transition boundaries are right-lateral strike-slip fault and left-lateral strike slip fault, respectively.

3. Data

The data analyzed in this study have been compiled from several sources. The earthquakes for the time period 1900–1992 come from the Global Hypocenter Data Base CD-ROM prepared by USGS (United States Geological Survey). The CD-ROM contains 19 catalogs related to the study area. For the time period 1993–2001, the preliminary determination of epicenters (PDE) data and Incorporated Research Institutions for Seismology (IRIS) data, which are available through Internet, are also used to update the data base. We have carried out our analysis in the area bounded by the co-ordinates 25–45° in longitude and by the co-ordinates 34–43° in latitude.

In order to estimate the seismic hazard parameters, Turkey has been divided into eight different regions as shown in Figures 1 and 3 taking different tectonic environments and epicenters of the earthquakes into consideration. The first region consists of the Marmara part of the NAF, the second region the Anatolian part of the NAF, the third region the NorthEast Anatolian Fault (NEAF) and the Caucasus, the fourth region the BZTZ and the EAF, the fifth region the earthquakes in relation to the Cyprus arc, the sixth region a part of the Aegean Arc, the seventh region the WAGC, and the eighth region the Mid Anatolian fault system (MAFS).

An earthquake data set used in seismicity or seismic risk studies must be homogenous. Namely, all earthquakes are defined in the same magnitude scale. To prepare a homogenous earthquake catalog, we have developed new relationships between different magnitude scales (m_b-body wave magnitude, M_S-surface wave magnitude, M_L-local magnitude, M_D-duration magnitude) and between surface wave magnitude and *I*-intensity for different regions of Turkey as shown in Figures 1 and 3. The m_b–M_S relationships calculated for each region using the orthogonal regression method is shown in Figure 2. Because the standard least squares method is based on the assumption that the values on the horizontal axis are estimated without errors, we applied the orthogonal regression method in the fitting of the relationships. Both methods are applied to data to show the differences between the fits for region 1. The dashed line represents the least squares fit and the solid lines show the orthogonal regression fits in Figure 2. All fits are listed in Table I and the uncertainty values are given in parentheses. In the case of deficiency of events, no relationship has been calculated for the regions where the number of earthquakes is less than 10. Consequently, using the relations given in Table I we have constructed a uniform catalog of M_S. The final data catalog consists of about 22600 earthquakes with magnitude 1.0 or greater.

Epicentral distribution of the earthquakes with surface wave magnitude 3 or greater is shown in Figure 3. The largest earthquakes (1939 Erzincan earthquake, $M_S = 7.8$; 1999 İzmit earthquake, $M_S = 7.8$ and 1999 Düzce earthquake, $M_S = 7.5$) that have occurred in Turkey during the last century are associated with the NAF.

4. Gutenberg–Richter Relationships and the Modal Values

The empirical relationship, known as Gutenberg–Richter (G–R) law, between the frequency of earthquake occurrences and magnitudes can be expressed as in the following formula:

$$\text{Log } N = a - bM,$$

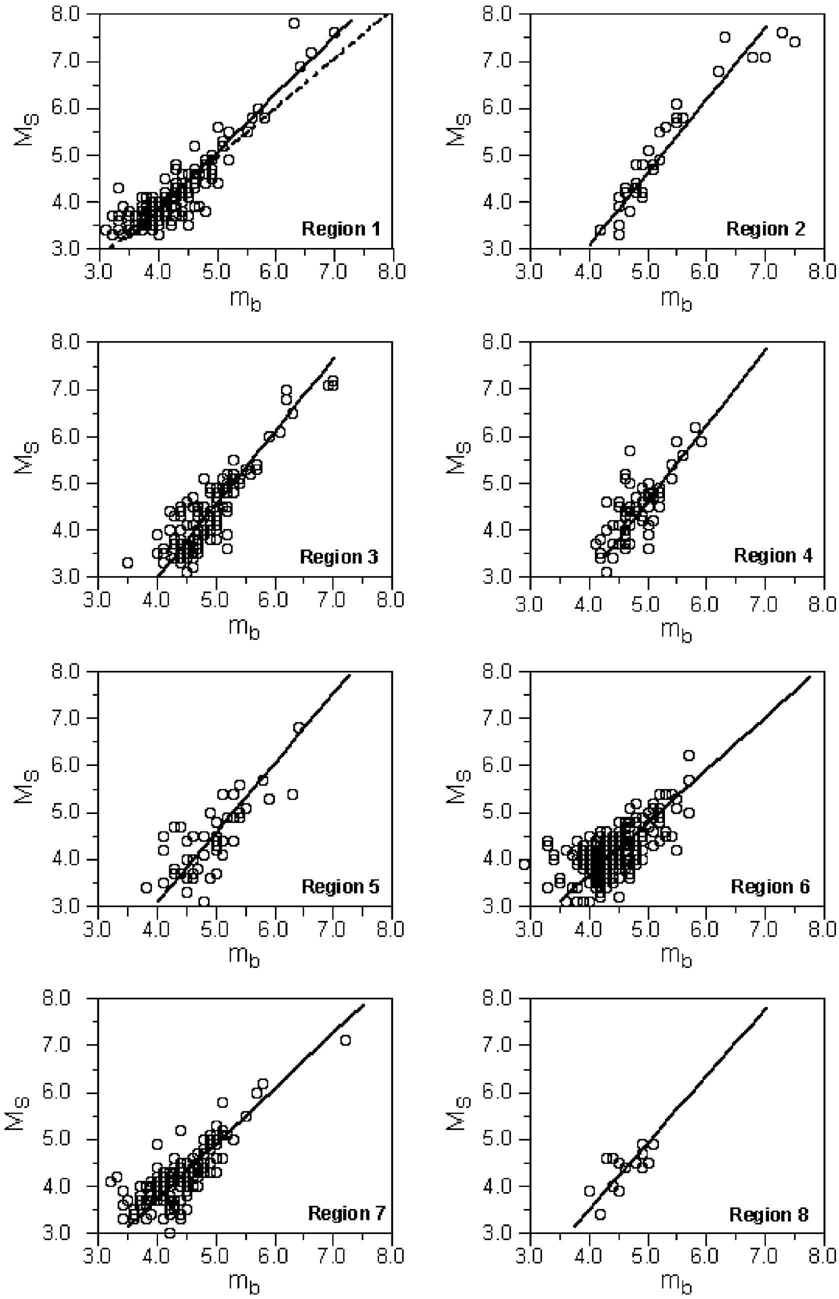

Figure 2. Relationships between m_b and M_S derived for eight different source regions in Turkey. The dashed line represents the least squares fit and the solid lines the orthogonal regression fits listed in Table 1.

Table I. Relationships between different magnitude scales and surface wave magnitude and intensity for eight different source regions in Turkey.

Region No.	Earthquakes No.	Calculated relationships
1	146	$M_S = 1.230(0.054) * m_b\text{-}1.068(0.115)$
2	36	$M_S = 1.550(0.090) * m_b\text{-}3.116(0.218)$
3	115	$M_S = 1.551(0.076) * m_b\text{-}3.196(0.173)$
4	67	$M_S = 1.613(0.134) * m_b\text{-}1.068(0.301)$
5	46	$M_S = 1.483(0.191) * m_b\text{-}2.847(0.430)$
6	232	$M_S = 1.119(0.065) * m_b\text{-}0.811(0.141)$
7	150	$M_S = 1.179(0.072) * m_b\text{-}0.948(0.154)$
8	14	$M_S = 1.424(0.394) * m_b\text{-}2.191(0.851)$
1	19	$M_S = 2.754(0.747) * M_L\text{-}8.524(1.625)$
2	1	–
3	0	–
4	5	–
5	14	$M_S = 0.904(0.135) * M_L\text{-}0.071(0.298)$
6	28	$M_S = 2.173(0.508) * M_L\text{-}5.865(1.101)$
7	19	$M_S = 1.936(0.280) * M_L\text{-}4.561(0.617)$
8	1	–
1	6	–
2	7	–
3	2	–
4	0	–
5	3	–
6	26	$M_S = 1.916(0.184) * M_D\text{-}4.711(0.402)$
7	17	$M_S = 2.733(0.681) * M_D\text{-}7.910(1.429)$
8	0	–
1	70	$M_S = 0.984(0.128) * I\text{-}1.756(0.381)$
2	43	$M_S = 2.613(0.732) * I\text{-}12.201(1.885)$
3	118	$M_S = 1.217(0.133) * I\text{-}3.464(0.348)$
4	53	$M_S = 1.146(0.755) * I\text{-}2.999(1.927)$
5	49	$M_S = 4.368(1.515) * I\text{-}25.145(3.961)$
6	14	$M_S = 1.037(0.067) * I\text{-}2.039(0.198)$
7	65	$M_S = 1.040(0.085) * I\text{-}2.541(0.245)$
8	17	$M_S = 2.051(0.720) * I\text{-}9.602(1.927)$
1	149	$m_b = 1.040(0.083) * M_L\text{-}0.164(0.168)$
2	2	–
3	3	–
4	33	$m_b = 1.155(0.174) * M_L\text{-}0.664(0.367)$
5	108	$m_b = 0.966(0.058) * M_L + 0.176(0.122)$
6	257	$m_b = 1.192(0.092) * M_L\text{-}0.725(0.190)$

Table I. (Continued.)

Region No.	Earthquakes No.	Calculated relationships
7	119	$m_b = 1.243(0.070) * M_L$-1.002(0.144)
8	4	–
1	85	$m_b = 1.156(0.134) * M_D$-0.539(0.271)
2	54	$m_b = 0.818(0.094) * M_D + 0.815(0.194)$
3	9	–
4	26	$m_b = 1.210(0.185) * M_D$-1.017(0.391)
5	57	$m_b = 1.067(0.133) * M_D$-0.283(0.271)
6	305	$m_b = 1.421(0.090) * M_D$-1.691(0.182)
7	114	$m_b = 1.399(0.128) * M_D$-1.632(0.260)
8	8	–

The relationships are calculated by the orthogonal regression method. The values in the parentheses show the uncertainties. These functional relations were used to construct a homogeneous catalogue.

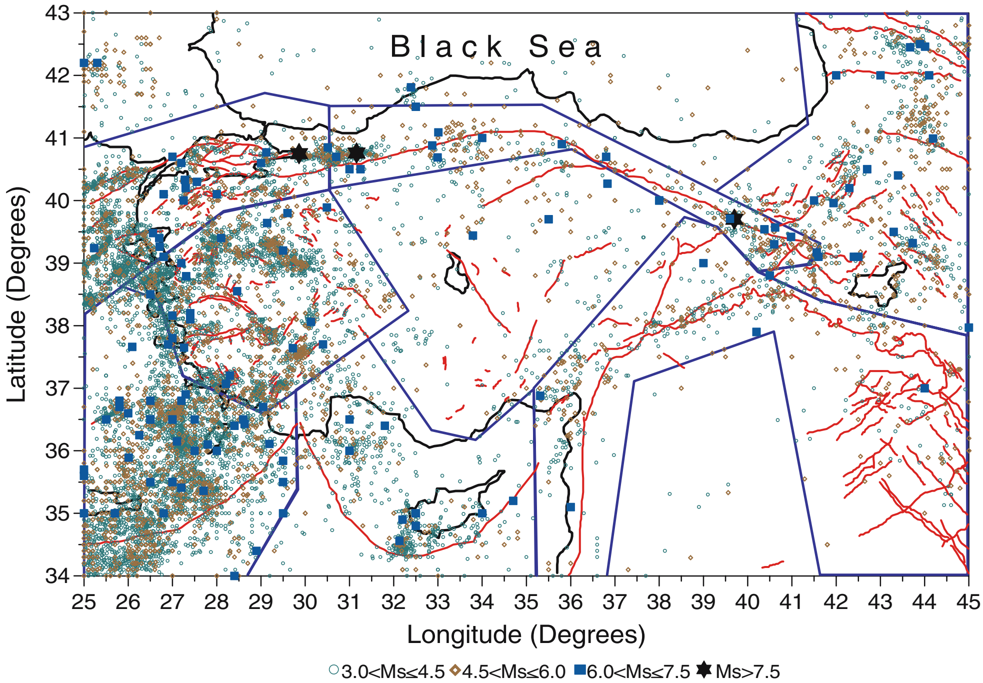

Figure 3. Epicenter locations of the earthquakes of $M_S \geq 3.0$ for the time period 1900–2001. Magnitude sizes of the earthquakes are shown by different symbols.

where N is the cumulative number of earthquakes with magnitude M and greater, a and b are constants. b is the slope of the frequency–magnitude distribution, and a is the activity level of seismicity. Gutenberg and Richter (1944) firstly estimated the constants known as seismicity parameters. The parameter a exhibits significant variations from region to region as it depends on the level of seismic activity, the period of observation, and the length of the considered area as well as the size of earthquakes. The parameter b related to tectonic characteristic of a region and properties of the focal material has been important in estimating seismic hazard.

We have used the least-squares method to estimate a and b-values. Generally, the G–R relationships give a straight line. Because of incompleteness in the record of small earthquakes, the data deviate from a straight line. Therefore, the relationships have been calculated for earthquakes larger than cut-off magnitudes (M_c) given in Table II for each region. The calculated G–R relationships are given in Figure 4. The largest a-value has been calculated in region 7, which has the highest seismic activity in the studied regions listed in Table II. The lowest b-value has been observed in regions of 2 and 1 where large and destructive earthquakes have occurred, respectively.

The a/b values provide detailed images of the local areas presented by high and low seismic zones (Yılmaztürk *et al.*, 1999; Bayrak *et al.*, 2002). The obtained a/b values for each region are given in Table II. It is observed that these values vary from 6.87 to 7.93. The highest values are computed in region 2, 1 and 6, respectively. These regions are related to the North Anatolian fault and the Aegean Arc where large earthquakes

Table II. Seismic hazard parameters derived for eight different source regions of Turkey for the time period 1900–2001.

Region	Earthquake no.	M_c	a/b	M_{max}	I_{max}	TE
1	4767	3.2	7.82	8.0	10.3	MPNAF
2	707	4.5	7.93	8.1	10.5	APNAF
3	807	4.3	7.66	7.8	10.1	NEAF–Caucasus
4	624	3.9	6.90	7.0	9.0	BZTZ–EAF
5	1116	4.2	6.85	6.9	8.8	Cyprus Arc
6	4341	3.8	7.70	7.8	10.0	Aegean Arc
7	8719	4.0	7.31	7.4	9.6	WAGC
8	305	4.6	6.87	6.9	8.9	MAFS

TE: Tectonic Environments; MPNAF: Western (Marmara) part of the North Anatolian Fault; APNAF: Anatolian part of the North Anatolian Fault; NEAF: North East Anatolian Fault; BZTZ: Bitlis-Zagros Thrust Zone; EAF: East Anatolian Fault; WAGC: Western Anatolian Graben Complexes; MAFS: Mid Anatolian Fault System.

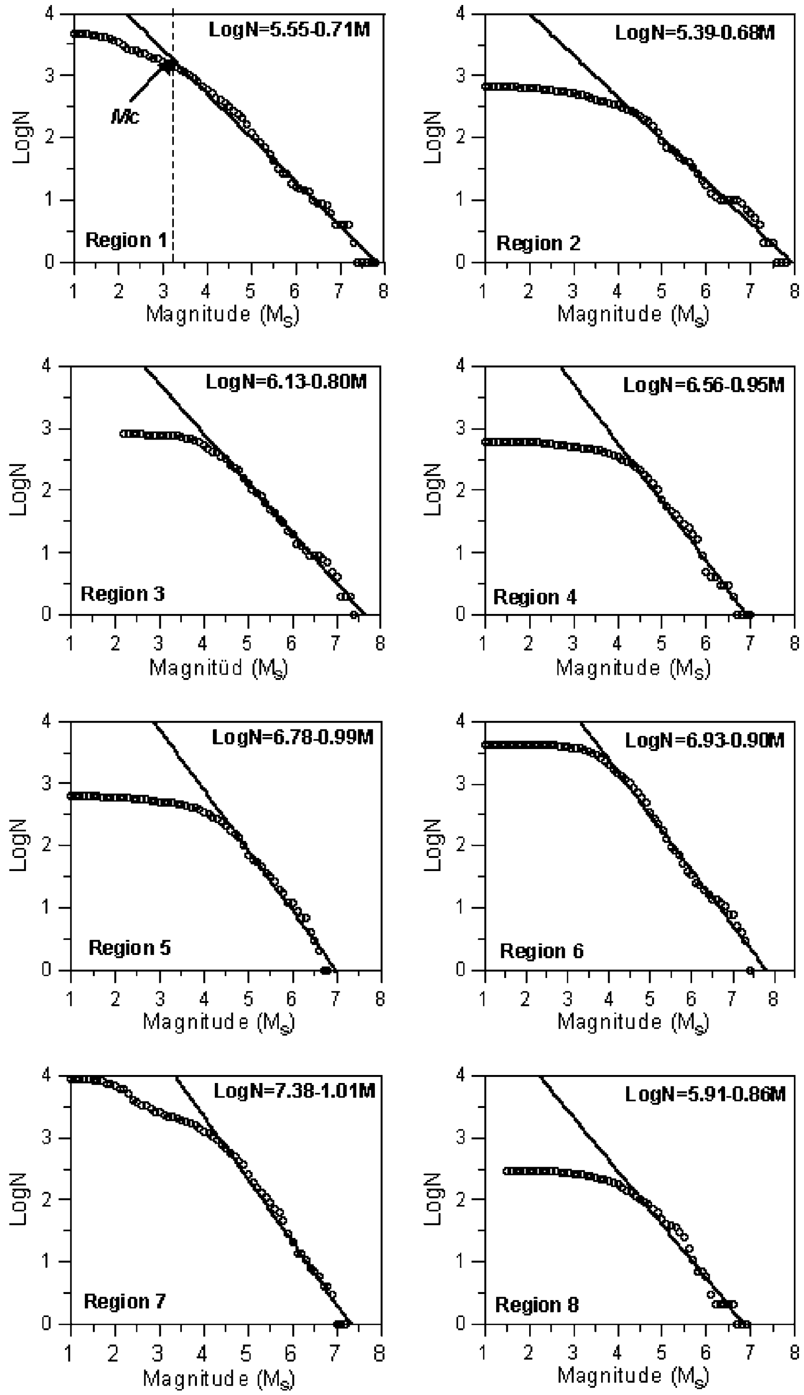

Figure 4. Gutenberg–Richter relationships for the different source regions in Turkey. M_c is cut-off magnitude.

have occurred as shown in Figure 3. The found value in region 8 is lower than those of other regions. This result proves the fact that the seismic activity level of region is low.

5. Expected Maximum Earthquake Magnitudes and Intensities

Gumbel's theory of extreme value has been used in statistical forecasting of maximum hazard parameters for a given region and time period. There are three asymptotic distributions of extremes. The asymptotes are (Makropoulos and Burton, 1986):

$$G^{I}(m) = \exp(-\exp(-\alpha(m-u))) \quad \text{or} \quad -\ln(-\ln G^{\mathrm{I}}(m)) = \alpha(m-u)\alpha > 0 \tag{2}$$

$$G^{II}(m) = \exp(-((u-m_0)/(m-m_0))^{k}) \quad k > 0, m \geq m_0, u > m_0 \geq 0 \tag{3}$$

$$G^{III}(m) = \exp(-((w-m)/(w-u))^{k}) \quad k > 0, m \leq w, u \tag{4}$$

Where m is the extreme magnitude, u is the mode of the distribution, w is the upper bound of extreme values and k is the curvature of the distribution. For the occurrence of maximum magnitude earthquakes, the use of the third type distribution of the extreme values is the best approximation to the data showing curvature with increasing magnitudes (Yılmaztürk and Burton, 1999).

The third type distribution of extremes fits to the observed maximum magnitude earthquakes and presents a physically realistic curvature at higher values. Therefore, Gumbel III distributions of earthquake occurrences are taken into account for the estimation of $M_{\max}$ and $I_{\max}$ for eight different source regions in Turkey. A nonlinear least squares method is used to estimate the parameters w, u, and k in Equation (4). Figure 5 demonstrates the distribution of Gumbel III and calculated nonlinear curves for each region.

In generally, seismic hazard maps are based on 10% of probability of exceedance in 50 years. This level of ground shaking has been used for designing buildings in high seismic areas. But different time intervals have been used in the seismic hazard studies. For example, Burton *et al.* (1984) used over a 75 years interval to produce the hazard maps showing the seismic risk in Turkey. Also, Harajli *et al.* (2002) evaluated the seismic hazard of Lebanon for 50 years and 100 years exposure time. Because the data used in this study consist of the earthquakes occurred in the last century, we used 100 years time interval in order to calculate the parameters for the different regions of Turkey.

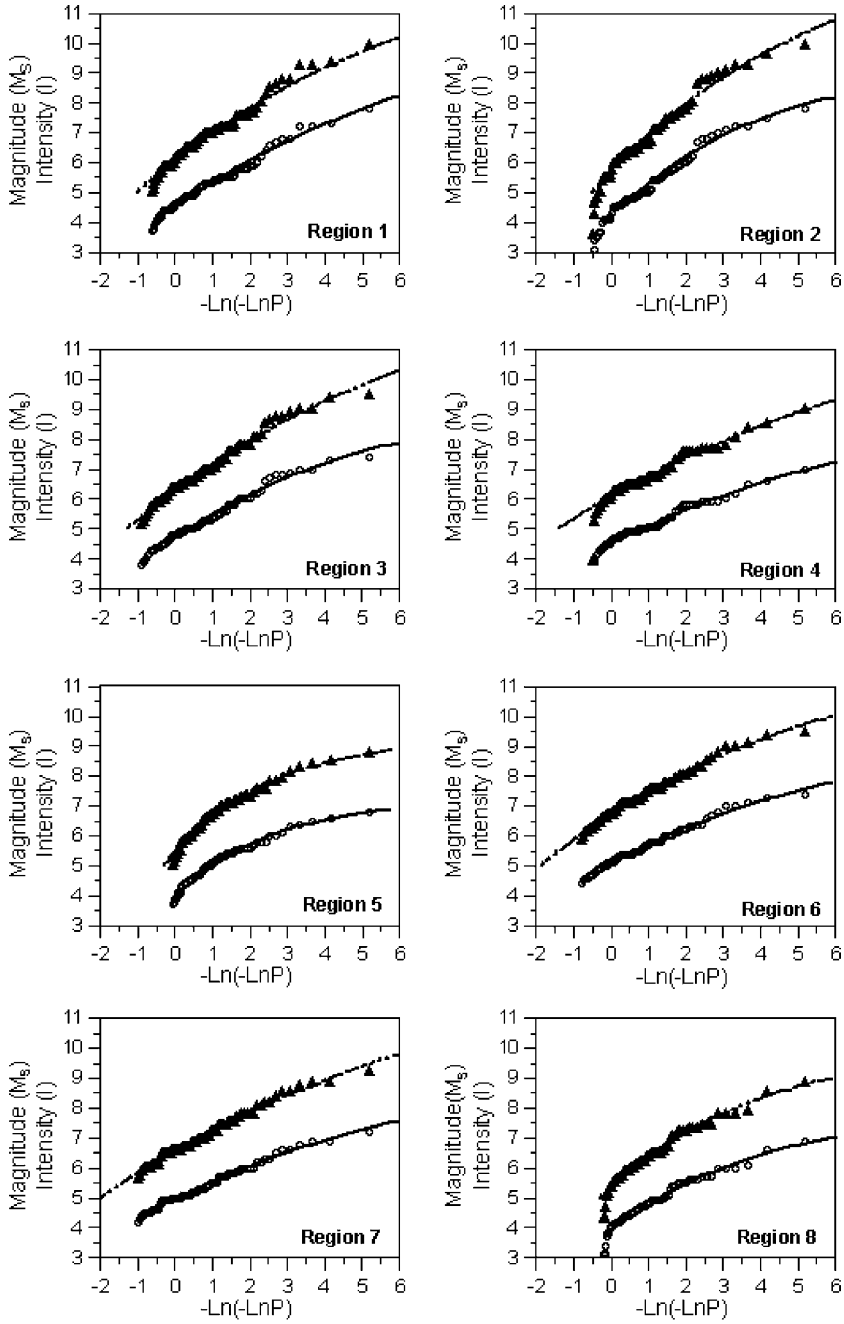

Figure 5. Distributions of Gumbel III for eight different source regions in Turkey. Triangles and circles represent I_{max} values and M_{max}, respectively. Curves are computed by using nonlinear least squares method. *P* indicates probability.

M_{max} and I_{max} values obtained in 100 years time spans are listed in Table II. In the case of no information about intensities for some earthquakes, the intensities have been estimated using the relationships given in Table I for each region. It is found that the M_{max} values are between 6.9–8.1 and I_{max} values between 8.9–10.5. As in the modal values, the highest maximum magnitudes and intensities have been observed in region 2, 1 and 6, respectively, while the lowest value has been found in region 8. These values are consistent with observed seismicity in the regions. The largest (1939 Erzincan, 1999 Gölcük and 1999 Düzce) earthquakes ($M_S \geq 7.5$) occurred in regions 1 and 2 (Figure 3). Also, a number of earthquakes of $6.0 \leq M_S$ observed in regions 1, 2 and 6.

The highest and the lowest values of all earthquake parameters (a/b, M_{max} and I_{max}) estimated in this study are observed in the same regions. It seems that these parameters are related to each other and we decided that the linear relations could be developed among these parameters. The relationships between M_{max}–a/b, I_{max}–a/b and I_{max}–M_{max} are shown in Figures 6, 7 and 8, respectively. Using the orthogonal regression method, the linear equations are found between the maximum magnitudes and the modal values,

$$M_{max} = 1.103(0.024) * a/b - 0.656(0.088) \quad (5)$$

between the maximum intensities and the modal values,

$$I_{max} = 1.482(0.058) * a/b - 1.286(0.213) \quad (6)$$

and between the maximum magnitudes and the maximum intensities

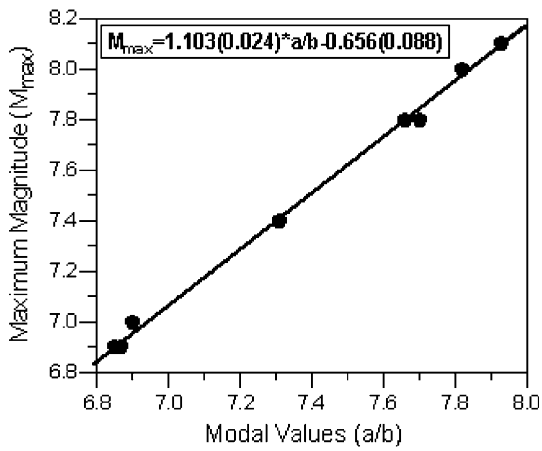

Figure 6. Relationship between a/b and M_{max} values for the different source regions in Turkey. The straight line is calculated by the orthogonal regression method.

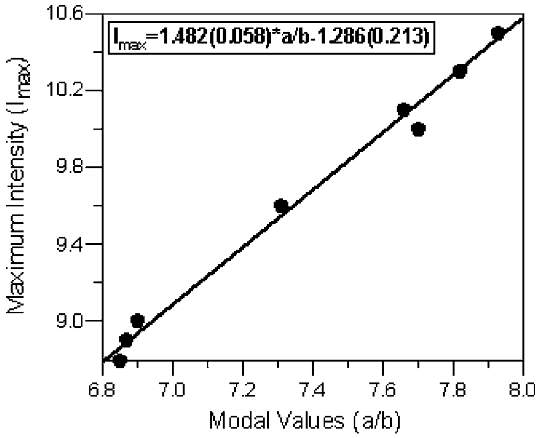

Figure 7. Relationship between a/b and I_{max} values for the different source regions in Turkey. The straight line is calculated by the orthogonal regression method.

$$I_{max} = 1.342(0.041) * M_{max} - 0.398(0.154) \tag{7}$$

The uncertainties in seismic hazard parameters are also given in the parentheses. In the case that one of the three parameters is known in a given region, two other unknown parameters can be estimated. For example, if a/b value is computed from G–R relation, the values of M_{max} and I_{max} could be empirically calculated using Equations (5) and (6) without being applied the Gumbel method. Thus, a set of the linear relations of 5, 6 and 7 can be used in the estimations of seismic hazard.

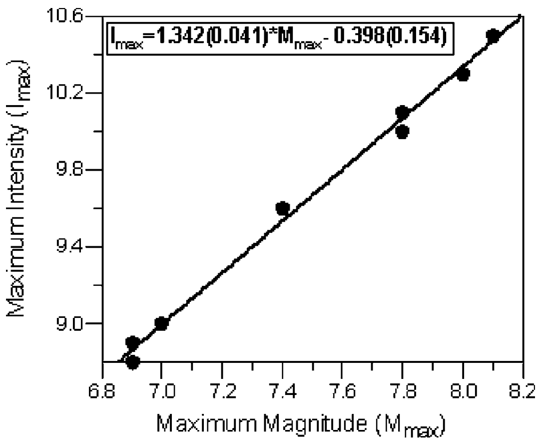

Figure 8. Relationship between M_{max} and I_{max} values for the different source regions in Turkey. The straight line is calculated by the orthogonal regression method.

6. Seismic Hazard Maps of Turkey

Mapping of seismic hazard parameters provides detailed knowledge about seismic activity observed in a given region. In this work, our approach for seismic hazard analysis has been based on the modal values, expected maximum magnitudes and intensities. The advantage of using these parameters for hazard studies is that it gives information about the active seismic zones. In order to produce the seismic hazard maps presented in Figures 9, 10 and 11, Turkey is divided into a grid point mesh 1° × 1°. The values of *a* and *b* are calculated by the least-squares method and *a*/*b* values have been computed for each grid. In order to demonstrate the applicable of the relationships between the seismic hazard parameters developed empirically in this study, M_{max} and I_{max} values shown in Figures 10 and 11 are found for each grid from the computed *a*/*b* values using Equations (5) and (6). Then, these values located in the center of grids are contoured.

It is observed that the computed *a*/*b* values increase towards the areas in which large and destructive earthquakes have occurred. The highest values are associated with the occurrence of great earthquakes along the NAF and Aegean Arc system. The reason for this is a large earthquake result in a decrease of the slope of the cumulative regression curve. Therefore, a low *b*-value to be much less than in the surrounding areas donates a high *a*/*b* ratio. Yılmaztürk *et al.* (1999) contoured the modal values in and around Turkey for the period 1964–1998. They used a grid point mesh 2° × 2° and observed the highest modal values on the NAF and Aegean region.

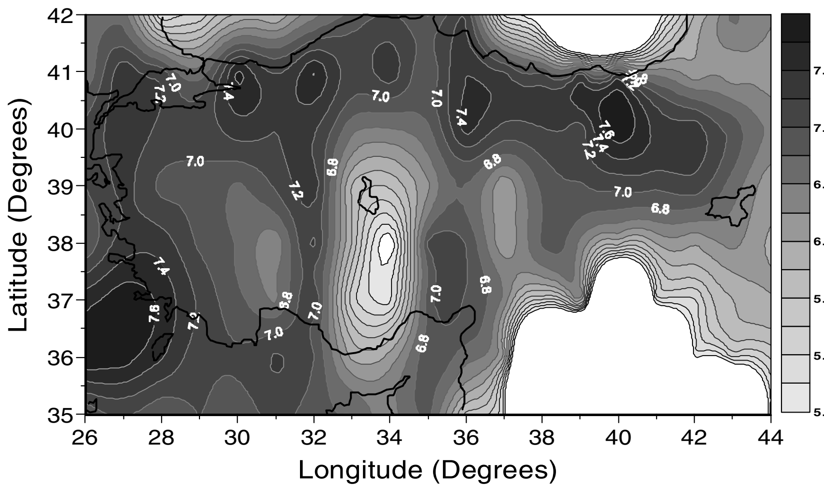

Figure 9. Contour map of *a*/*b* values computed in a grid of equally spaced points at 1° in 100 years time intervals.

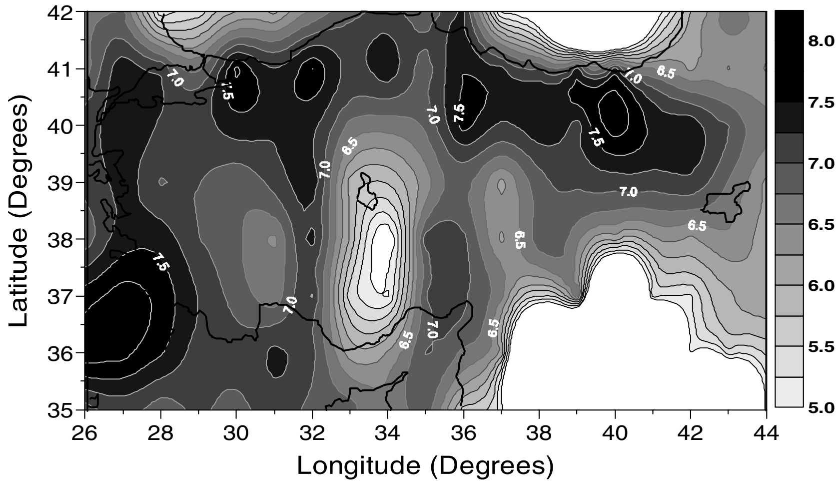

Figure 10. Contour map of the maximum magnitudes computed empirically from Equation (5) in a grid of equally spaced points at 1° in 100 years time intervals.

Figures 10 and 11 show the contour maps of empirical M_{max} and I_{max} values, respectively. Since there are linear relations between three parameters as shown in Figures 6, 7 and 8, low and high contour levels are found in the same areas. The estimated maximum values of M_{max} and I_{max} value are 7.75 and 10, respectively. The higher values have been observed in Erzincan, İzmit and the Aegean Arc and the lower values have been found in the same regions as seen in Figures 10 and 11.

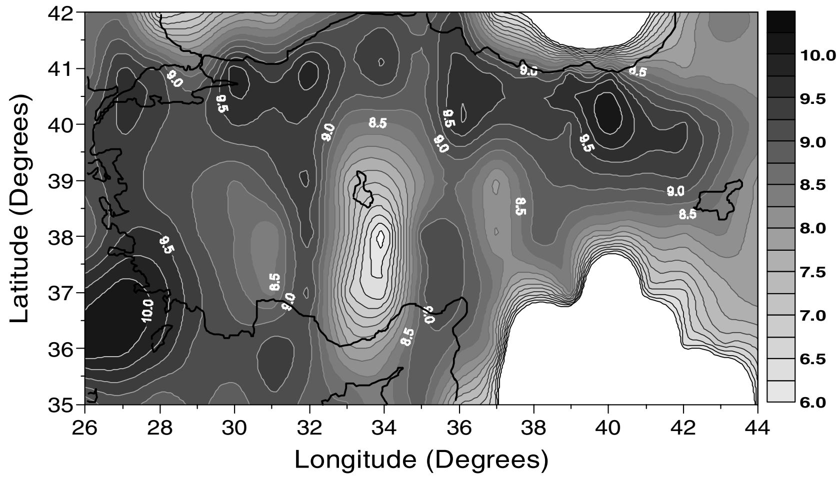

Figure 11. Contour map of the maximum intensities computed empirically from Equation (6) in a grid of equally spaced points at 1° in 100 years time intervals.

Burton *et al.* (1984) produced hazard maps to show the seismic risk in Turkey using the data for 1900–1978 and observed a similarity in the contour maps emphasizing the relative risk associated with the NAF. Although the NAF is clearly dominant in their maps there is a spur of seismicity that may be contoured tenuously corresponding to the EAF and in terms of seismic risk resolution herein extends through to a relative high in Cyprus. Also, a noteworthy but somewhat dubious feature is the extreme high for their maps in the west Hellenic Arc. They determined the hazard maps from cells of seismicity of 4°, but we used 1°. So, our contour maps are localized in some areas such as İzmit, Düzce-Bolu, Tosya, Ladik and Erzincan associated with tectonics of the NAF. Because their catalog does not include the damaging Erzincan ($M_S = 6.8$) earthquake of 1992, İzmit ($M_S = 7.8$) and Düzce ($M_S = 7.5$) earthquakes of 1999, the maps of seismic hazard parameters in their study are inadequate to show the recent seismic hazard of MPNAF and APNAF. So, there are general differences between their maps and our maps including the recent seismicity of Turkey. The largest earthquake magnitudes expected over a period of seventy-five years is 7.25 from their maps, whereas we calculated this value above 7.5 for the period of one hundred year in and around İzmit and Erzincan. Also, we observed high values around Ladik. While they observed a contour level of 7.0 in the southeast of Lake Van, we found about 6.5 in this area. The contour level of 7.0 around Adana is related to Adana–Ceyhan ($M_S = 6.3$) earthquake of 1998.

Erdik *et al.* (1999) carried out a probabilistic seismic hazard analysis for Turkey and neighboring regions. They computed the highest acceleration values in the NAF and the EAF using the historical and instrumental data. We did not observe similar results for the EAF. This may be a result of not using the historical data in this study. High values of all three estimated parameters imply that seismic hazard depends on magnitude size and seismic activity level in the study area.

7. Conclusions

The Global Hypocenter Data Base (CD-ROM) for the time period 1900–1992, PDE data and IRIS data for the time period 1993–2001 have been used to analyze the relations between the hazard parameters of a/b, M_{max}, and I_{max}. For this purpose, Turkey has been divided into eight different regions by means of tectonic environments and epicenters of the earthquakes and these parameters have been calculated for each region.

The highest a-values are observed in the Aegean region, but the lowest b-values are estimated for the North Anatolian Fault. The highest values of the a/b, M_{max}, and I_{max} are associated with regions 2, 1, and 6 containing the North Anatolian Fault and the Aegean Arc, respectively. The hazard parameters estimated for region 8 (Figure 1) are lower than those estimated for other regions. Since these results are in agreement with seismicity of the regions, it can be said that the calculated values reflect strongly high and low seismicity. It is found that all three parameters are related to each other between for different regions of Turkey. We have developed the linear equations among these hazard parameters using the orthogonal regression method. The maps of $M_{\max}$ and $I_{\max}$ are produced from a/b values using the empirical relationships developed in this study. The highest values of the computed parameters are observed in and around Erzincan, İzmit, Ladik, Tosya, Sakarya, Bolu, and Düzce. The moderate values are associated with the EAF, the BZTZ, the WAGC, the Cyprus arc and the Caucasus.

The high values of three estimated parameters imply that seismic hazard depends on magnitude size and seismic activity level in the considered area. In connection with these parameters, it can be emphasized that the maps of maximum magnitude and intensity produced empirically in this study reflect the tectonic and seismicity properties of any undertaken region, as well as the map of modal values computed from G–R relationship. The maps indicate the areas where large and destructive earthquakes have occurred and it can be used successfully in seismic hazard studies.

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References

Båth, M.: 1981, Earthquake recurrence of a particular type, *PAGEOPH* **119**, 1063–1076.

Bayrak, Y., Yılmaztürk, A., and Öztürk, S.: 2002, Lateral variations of the modal (a/b) values for the different regions of the world, *J. Geodynamics* **34**, 653–666.

Bender, B.: 1983, Maximum likelihood estimation of b values for magnitude grouped data, *Bull. Seism. Soc. Am.* **73**(3), 831–851.

Burton, P. W..: 1979, Seismic risk in southern Europe through to India examined using Gumbel's third distribution of extreme values, *Geophys. J. R. Astr. Soc.* **59**, 249–280.

Burton, W. P.., McGonigle, R.., Makropoulos, K. C., and Üçer, S. B.: 1984, Seismic Risk in Turkey, the Aegean and eastern Mediterranean: The occurrence of large magnitude earthquakes, *Geophys. J. R. Astr. Soc.* **78**, 475–506.

Dewey, J. F.: 1976, Seismicity of Northern Anatolia, *Bull. Seism. Soc. Am.* **66**, 843–868.

Erdik, M., Doyuran, V., Akkaş, N., and Gülkan, P.: 1985, A probabilistic assessment of the seismic hazard in Turkey, *Tectonophysics* **117**, 295–344.

Erdik, M., Alpay B. Y., Onur, T., Sesetyan, K., and Birgoren, G.: 1999, Assessment of earthquake hazard in Turkey and neighboring regions, *Annali di Geofisica*, GSHAP Summary Volume.

Epstein, B. and Lomnitz, C.: 1966, A model for the occurrence of large earthquakes, *Nature* **211**, 954–956.

Gumbel, E.: 1958, *Statistics of extremes*, Clombia University Press, New York, 375 pp.

Gutenberg, B. and Richter, C. F.: 1944, Frequency of earthquakes in California, *Bull. Seism. Soc. Am.* **34**, 185–188.

Harajli, M., Sadek, S., and Asbahan, R.: 2002, Evaluation of seismic hazard of Lebanon, *J. Seismol.* **6**, 257–277.

Kasapoğlu, K. E. and Toksöz, M. N.: 1983, Tectonic consequences of the collision of the Arabian and Eurasian plates: Finite element models, *Tectonophysics* **100**, 71–95.

Lilwall, R. C.: 1976, Seismicity and seismic hazard in Britain, *Inst. Geol. Sci. Seism.* Bull. No. 4, HMSO, London.

Makropoulos, K. C. and Burton, P. W.: 1986, Hazan: A FORTAN program to evaluate seismic-hazard parameters using Gumbel's theory of extreme value statistics, *Comp. Geosci.* **12**, 29–46.

McKenzie, D. P.: 1970, Plate tectonics of the Mediterranean region, *Nature* **226**, 239–243.

Miyamura, S.: 1962, Magnitude-frequency relations and its bearing on geotectonics, *Proc. Jap. Acad.* **38**, 27–30.

Nordquist, J. M.: 1945, Theory of largest values applied to earthquakes magnitudes, *Trans. Am. Geophys. Un.* **26**, 29–31.

Olsson, R.: 1999, An estimation of the maximum b-value in the Gutenberg–Richter relation, *Geodynamics* **27**, 547–552.

Papazachos, B., Kiratzi, A., and Papadimitriou, E.: 1991, Regional focal mechanism for earthquakes in the Aegean area, *PAGEOPH* **136**(4), 405–420.

Tsapanos, T. M. and Papazachos, B. C.: 1998, Geographical and vertical variation of the earth's seismicity, *J. Seismol.* **2**, 183–192.

Yarar, R., Ergünay, O., Erdik, M., and Gülkan, P.: 1980, A preliminary probabilistic assessment of the seismic hazard in Turkey, *Proc. 7th World Conf. Earthquake Eng., Istanbul*, 309–316.

Yegulalp, T. M. and Kuo, J. T.: 1974, Statistical prediction of the occurrence of maximum magnitude earthquakes, *Bull. Seism. Soc. Am.* **64**, 393–414.

Yılmaztürk, A., Bayrak, Y., and Çakır, Ö.: 1999, Crustal seismicity in and around Turkey. *Nat. Hazards*, **18**, 253–267.

Yılmaztürk, A. and Burton, P. W.: 1999, An evaluation of seismic hazard parameters in southern Turkey, *J. Seismol.* **3**, 61–81.