ANNALI DI GEOFISICA, VOL. 42, N. 6, December 1999

Assessment of earthquake hazard in Turkey and neighboring regions

Mustafa Erdik, Yesim A. Biro, Tuna Onur, Karin Sesetyan and Gulum Birgoren
Bogazici University, Kandilli Observatory and Earthquake Research Institute, Cengelkoy, Istanbul, Turkey

Abstract
The aim of this study is to conduct a probabilistic seismic hazard analysis for Turkey and neighboring regions, using the most recently developed attenuation relationships. The seismicity database is compiled from numerous sources, and the tectonic setting of the region has been studied in detail. Utilizing these two major categories of information together with the selected attenuation relationships, the seismic source zones are determined, and PGA contour maps are produced for specific return periods. The study is intended to serve as a reference for more advanced approaches and to stimulate discussion and suggestions on the database, assumptions and the inputs, and to pave the way for the probabilistic assessment of seismic hazard in the site selection and the design of engineering structures.

Key words *seismic hazard assessment – earthquakes – Turkey – Aegean Sea – North-Anatolian Fault – UN/IDNDR*

1. Introduction

Seismic hazard analyses aim at assessing the probability that the ground motion parameter at a site due to the earthquakes from potential seismic sources will exceed a certain value in a given time period.

Apart from the numerous studies of local or regional scale, the studies of Alsan (1972), Gencoglu and Tabban (1973), Båth (1979) and Hattori (1979) have addressed the problem of assessment of seismic hazard in Turkey through the statistical manipulation of the past instrumental earthquake data with no consideration of the seismic source regionalization. Within the context of the UNESCO project titled «Survey of the Seismicity of the Balkan Region», a rather elaborate probabilistic seismic hazard assessment was carried out for Western Turkey (Algermissen *et al.*, 1974). More comprehensive studies on the subject matter have been conducted by Yarar *et al.* (1980), Erdik and Oner (1982), Erdik *et al.* (1982, 1985) and Gulkan *et al.* (1993). The maps provided in Erdik *et al.* (1985) contain probabilistic estimates of the maximum MSK intensity, and maximum horizontal peak ground acceleration for return periods of 225, 475 and 10000 years. The study reported herein was conducted in connection with the Global Seismic Hazard Assessment Program (GSHAP, see Giardini and Basham, 1993).

Turkey lies within the Mediterranean sector of the Alpine-Himalayan orogenic system, which extends from Italy to Burma. This system, identified with high mountain ranges and shallow, somewhat diffuse seismicity, constitutes one of the most seismically active continental regions of the world with a long and well documented history of earthquakes.

Portrayal of the seismicity and the tectonics of a region provides the essential information towards the assessment of seismic source zones.

Mailing address: Dr. Mustafa Erdik, Bogazici University, Kandilli Observatory and Earthquake Research Institute, 81220 Cengelkoy, Istanbul, Turkey; e-mail: erdik@hamlin.cc.boun.edu.tr

Almost all earthquakes in Turkey and its vicinity are associated with tectonic elements. The correlation of seismicity with the tectonic elements (seismo-tectonics) constitutes an important phase of earthquake hazard assessment and, as such, several micro-plate tectonics models have been proposed.

The bulk of Anatolia, Aegean Sea and Cyprus is located on the Anatolian (or Turkish) plate. The northern boundary of the Anatolian plate is the Anatolian trough and the right-lateral, strike-slip North Anatolian Fault (NAF). The southern boundary of the Anatolian plate is formed by the Hellenic arc, south of Cyprus and the East Anatolian Fault (EAF), which joins the NAF at Karliova. The EAF, located between the Gulf of Iskenderun and Karliova, is a left lateral, strike-slip fault. The south-westward motion of the Anatolian plate, relative to Africa, is taken up by the subduction along the Hellenic trench. In Western Anatolia, the east-west trending grabens account for most of the seismic events of this region. The area encompassing Turkey, from the Aegean region in the west to the Caucasus in the east comprises many major seismically active regions. The Aegean region, the Caucasus, the North Anatolian Fault Zone and the East Anatolian Fault Zone are the most well known among these, where countless damaging earthquakes have occurred throughout history.

The seismicity compilations are based on the specially-compiled catalogs of historical and instrumental data. Attention is paid to the cross-correlation of instrumental and historical earthquake data. Uniformity in magnitude is implemented by converting all magnitudes to moment magnitude. The data is biased with respect to the reporting periods and magnitude ranges, and can only be considered to be homogenous for magnitude 4 and above for the last several decades.

Seismic sources are identified by using the macro-seismic locations of historic earthquakes and instrumental locations of the last 50 years' earthquakes. Delineation of the source boundaries is based on neo-tectonic elements and sudden variations in the homogeneity of the seismicity. All together 37 earthquake source zones were identified. In addition several background seismic zones are defined to account for floating earthquakes not accounted by these sources and also to delineate zones where no significant earthquake has taken place for centuries.

For the assessment of the recurrence relationships in these source zones the rates of occurrence in different magnitude groups are adjusted by determination of the period over which the data in a given magnitude group are completely reported.

For depicting earthquake ground motion severity, predictive empirical relationships for MSK intensity (attenuation relationships developed for Eastern Turkey and tested for Northern Iran), peak ground accelerations and spectral amplitudes at the periods of 0.2 s and 1 s and for different site classes are considered. However in this paper only the results for peak ground acceleration on competent soil corresponding to 10% probability of exceedance in 50 years are presented.

For the probabilistic hazard analysis SEISRISK III (Bender and Perkins, 1987) routine, in-house improved with graphical pre- and post-processors, was used. The stochastic model used in this routine assumes that the generation of earthquakes in the time domain follows a homogenous Poisson process. The pros and cons of this assumption are discussed. The routine allows for variability of the source boundaries. A sensitivity analysis conducted indicated that this effect is not important considering the return periods and the geometry of the sources.

2. Methodology

The evolution of seismic hazard assessment can be traced in five generations of methodology (Muir-Wood, 1993). These are: historical determinism; historical probabilism; seismotectonic probablisim; non-Poissonian probabilism; and earthquake prediction. The seismotectonic probabilism method of hazard assessment used in this study does not rely solely on historical seismicity records but combines it with geological knowledge, that is, the data of paleoseismic ground motions and data of neotectonic faulting, and with the scientific seismotectonic understanding of earthquake causes. These data are combined through a seismic source model, but the uncertainty in the determination of the input parameters is incorporated in the form of a weighted range of values.

The general methodology in calculating seismic hazard is well established in literature (*e.g.*, Cornell, 1968). The method involves two separate models: a seismicity model describing geographical distribution event sources and the distribution of magnitudes, and an attenuation model describing the effect at any site given as a function of magnitude and source-to-site-distance. The seismicity model may comprise a number of source regions, the seismicity of which should be expressed in terms of a recurrence relationship of events with magnitudes greater or equal to a certain value. The attenuation model relates the earthquake intensity (*i.e.* the effect of it, as a general term) at a site to magnitude, distance, source parameters and site conditions.

For forecasting seismic occurrences numerous models have been developed. The simplest stochastic model for earthquake occurrences is the Homogeneous Poisson Model, which is used in this study. For the earthquake events to follow that model, the following assumptions are in order: earthquakes are spatially independent; earthquakes are temporally independent; and probability that two seismic events will take place at the same time and at the same place approaches zero.

Although not specifically required in the SEISRISK III program utilized, the recurrence relationship of the events is expressed with the help of the empirical relationship first defined by Gutenberg-Richter: $\log N = a + bM$, where N is the number of shocks with magnitude greater or equal to M per unit time and unit area, and a and b are regression parameters the seismic source region considered. Using an application of the total probability theorem the probability per unit time that that ground motion amplitude a^* is exceeded can be expressed as follows (McGuire, 1993b):

$$P[A > a^* \text{ in time } t]/t = \tag{2.1}$$

$$= \sum_i \nu_i \int\int G_{A|m,r}(a^*) f_m(m) f_r(r|m)\, dm\, dr$$

where $P[I \leq i \mid m, r]$ is the probability that the maximum effect I is less than i. Given m and r, $f_m(m)$ is the probability density function for magnitude, $f_r(r|m)$ and is the probability distribution function for distance. $f_r(r|m)$ is dependent on the geometric nature of the source.

3. Tectonic setting

Turkey lies within the Mediterranean sector of the Alpine-Himalayan orogenic system, which runs west east from the Mediterranean to Asia. The Alpine orogeny is produced as a result of the compressional motion between Europe and Africa, whereas the Himalayan orogeny has resulted from the India-Asia collision. Turkey is surrounded by three major plates: African, Eurasian, and Arabian, and two generally acknowledged minor plates: Aegean and Anatolian, as shown in the neo-tectonic models of McKenzie (1972) and Dewey *et al.* (1973) presented in figs. 1a,b.

In his widely accepted model, McKenzie (1972) divided the region into three additional small plates (Iranian, South Caspian, and Black Sea) apart from the three major and two minor plates. His sketch of plate boundaries and motions is given in fig. 1a. The arrows indicate the directions of motion relative to Eurasia and their lengths are approximately proportional to the magnitude of relative velocity. Plate boundaries across which extension is taking place are shown by a double line, transform faults by a single heavy line and boundaries across which shortening is occurring by a solid line crossed by short lines at right angles. The African plate is moving northwards towards the Eurasian plate, pushing the Turkish plate in a westward motion. The North Anatolian Fault and the East Anatolian Fault constitute the northern and southern boundaries, respectively, of this plate, while the southern boundary is not well defined by seismicity.

East of 20°E the motion between Africa and Eurasia is not taken up on one plate boundary, but is carried by the motion of the Aegean and Turkish plates. The boundary between the Aegean and Turkish plates forms a north-south trending belt of seismicity across Western Tur-

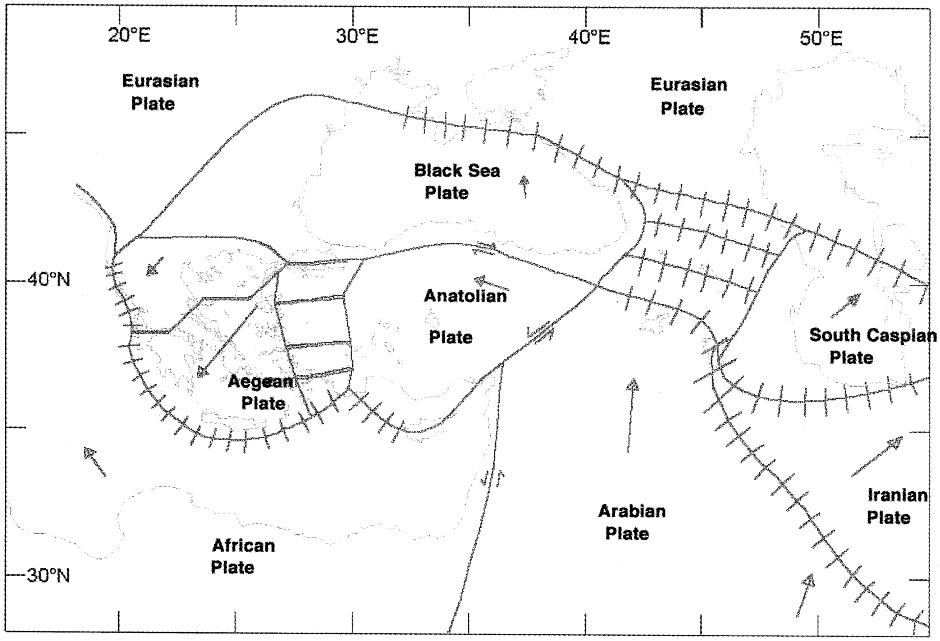

Fig. 1a. Tectonic features (after McKenzie, 1972).

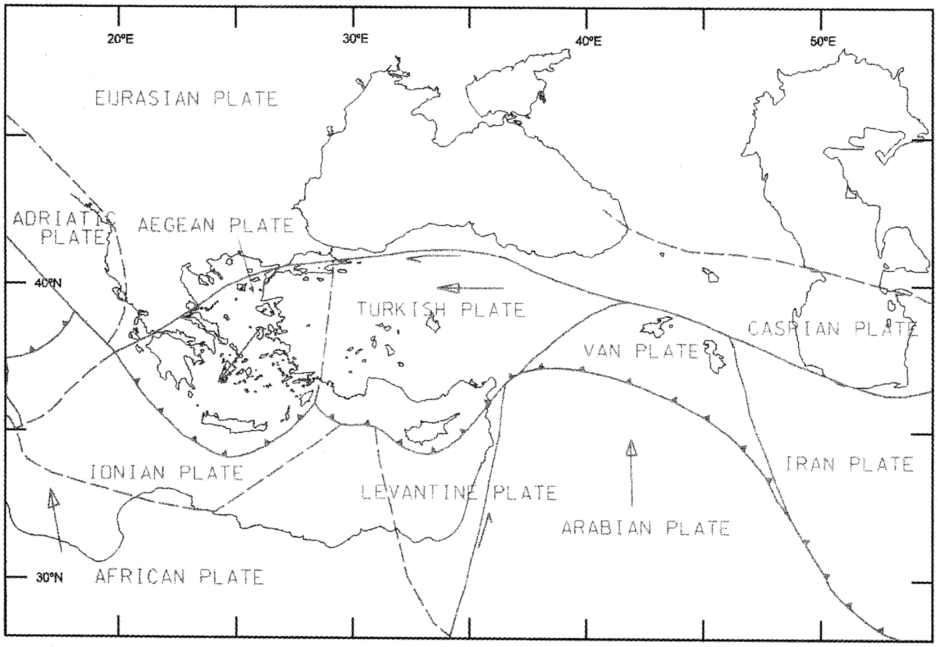

Fig. 1b. Neotectonic setting of the Alpine system (Dewey *et al.*, 1973).

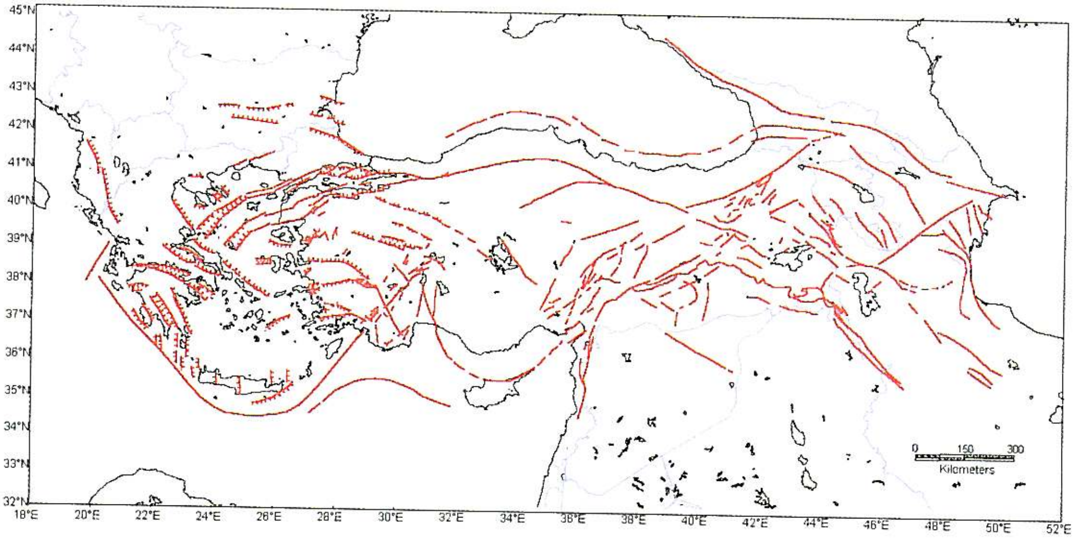

Fig. 2. Major tectonic features of the region.

key and the Eastern Aegean. The Aegean plate is moving towards the southwest relative to the European plate, producing extension and strike-slip motion along the boundary between the two plates. The southern boundary of the Aegean plate is moving southwest relative to the African plate, and is overthrusting the Mediterranean Sea floor. At the eastern end of the Turkish plate, the motion is taken up by thrust faults associated with the Caucasus. The result of this geometry is a thickening of the continent throughout the active region, which continues to elevate the Caucasus. Thrusting in Eastern Turkey and the Caucasus changes to strike-slip motion between the Turkish and Eurasian plates at the eastern outset of the North Anatolian Fault Zone. McKenzie (1972) conjectures that the relative motion between the Black Sea and the Eurasian plate must be in a north-south direction with the Black Sea moving towards Eurasia, though rather slowly, since the seismicity of this boundary has been low for most of this century.

The major tectonic elements of Turkey adopted after Barka (1992) are shown in fig. 2.

4. Seismicity

Various catalogues of historical and instrumental seismicity of the region have been analyzed and combined to form a historical seismicity map of the region, to be used afterwards in the delineation of the seismic source zones. For source seismicity assessments the seismicity data have been considered in two categories: pre-1963, and post-1963. The pre-1963 data are considered complete for earthquakes $M > 5.5$, whereas post-1963 data are considered complete for earthquakes of $M > 4.0$.

There are several earthquake catalogues available for the region from both national and international sources. Turkish references include those compiled by Kandilli Observatory and Earthquake Research Institute of Bogazici University (Istanbul), Istanbul Technical University (Istanbul) and the General Directorate of Disaster Affairs of the Turkish Government (Ankara). International sources are: Ambraseys (1988); PDE/NEIC (Preliminary Determination of Epicenters/National Earthquake Information Center); ISC (International Seismological Center);

ISS (Bulletin of International Seismology Summary); BCIS (Bureau Central International Sismologique); EMSC (European-Mediterranean Seismological Center); CNSS (US Council of the National Seismic System), Unified Catalogue of Earthquakes of Northern Eurasia. Instrumental part 1900-1990) (instrumental data: under supervision of N.V. Kondorskaya, macroseismic data: under supervision of N.V. Shebalin, Balassanian *et al.*, 1999) and the earthquakes of Greece (Papazachos and Papazachou, 1997).

In the traditional probabilistic seismic hazard assessment (Cornell, 1968) chosen by GSHAP, independent events must be treated. To satisfy this requirement earthquakes in the study region need to be de-clustered by removing foreshocks and aftershocks from the seismicity databases in order to obtain a Poissonian distribution. In this study, mainly earthquakes with $M > 5.5$ were used for recurrence relations, therefore the removal of fore- and after-shocks was not necessary to ensure Poissonian distribution, since fore- and after-shocks are seldom of greater magnitude. In addition, for Turkey it was observed that removal of the fore- and after-shocks did not produce a significant difference in the analytical results, except in some areas where the earthquakes cause long series of aftershocks, like North Anatolian Fault Zone, and some parts of the Aegean region, which were considered insignificant once the earthquakes with $M < 5.5$ earthquakes are eliminated for the assessment of recurrence relationships.

The seismicity data from different catalogs were provided in different magnitude scales. For numerous earthquakes there were more than one value, sometimes in different magnitude scales, taken from different sources. This was quite beneficial for comparing the magnitude scales. In the case of older earthquake records (roughly prior to 1970), the types of magnitudes were often not defined. However, after comparing those magnitudes with other magnitude scales when both were available, it was observed that the values in undefined magnitude scales corresponded best with M_S (surface wave magnitude) values. The moment magnitude M was used as the general magnitude unit because as suggested by various researchers the use of moment magnitude avoids the «saturation» of the more traditional band-limited magnitude measures at large seismic moments and, therefore is a better measure of the true size of an earthquake, and as described in the following chapters moment magnitude is recommended to be used with the attenuation relationships.

As representative plots of seismicity, the epicentral distribution of the pre-1963 and post-1963 earthquakes are presented in figs. 3a,b.

5. Seismic source zonation

A seismic source zone is defined as a seismically homogenous area, in which every point within the source zone is assumed to have the same probability of being the epicenter of a future earthquake. An ideal delineation of seismic source zones requires a complete comprehension of the geology, tectonics, paleoseismology, historical and instrumental seismicity, and other neotectonic features of the region under study. However, it is not always possible to compile detailed information in all these fields for most of the world. Thus, frequently, seismic source zones are determined with two fundamental tools; a seismicity profile and the tectonic regime of the region under consideration. Although seismic source zonation is a widely used methodology to determine earthquake hazard, it is not the only approach. Since delineation of the seismic source zones still remains rather subjective, at present researchers (*e.g.*, Frankel, 1995) are suggesting other methods for evaluating seismic hazard, in order to eliminate the subjectivity of this procedure. This is particularly important in areas where the tectonic structure is very fragmented and the seismicity is diffuse. Whereas in most regions of Turkey, the seismicity is relatively well documented, major faults are often well defined and the source zones are fairly obvious. Hence it is considered adequate to use the conventional method of seismic source zonation for Turkey in this study.

Seismic source zones used in this study are defined according to the principles that: source

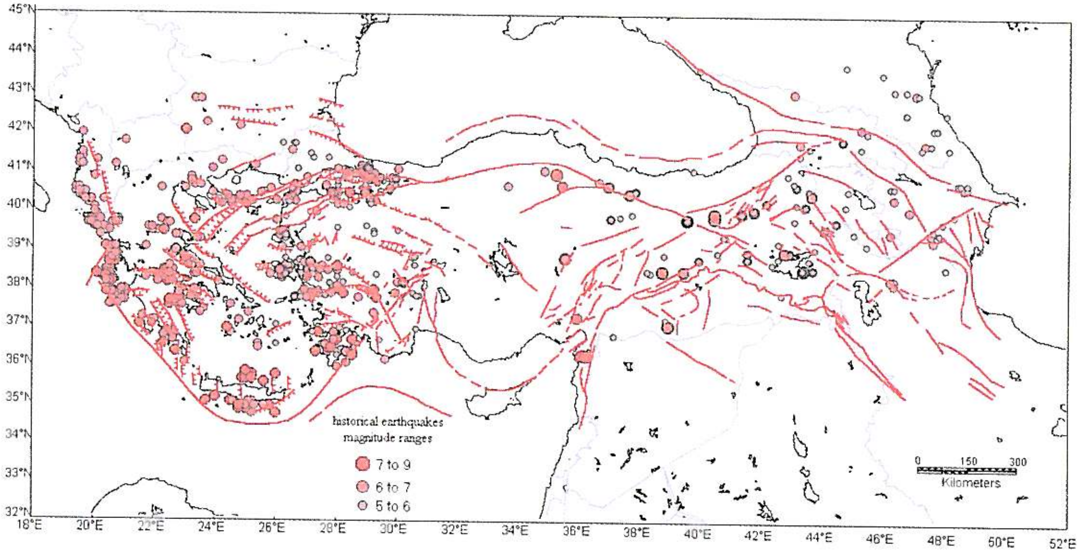

Fig. 3a. Historical seismicity with the major tectonic features.

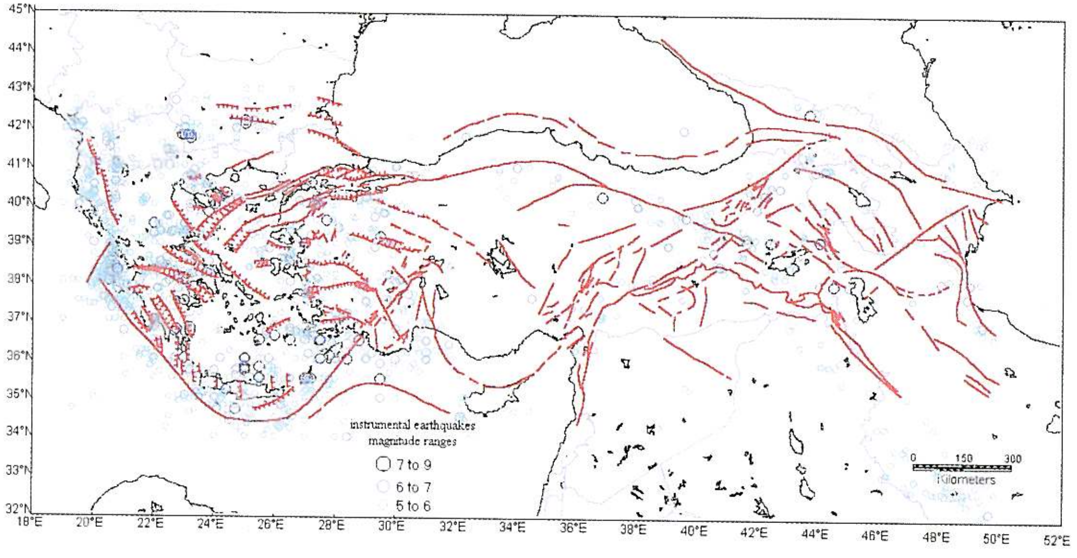

Fig. 3b. Instrumental seismicity with the major tectonic features.

boundaries should be defined with regard to the subsequently applied seismic hazard methodology; sources (or regions) should be defined as areas with seismic characteristics which are as homogeneous as possible; between sources (regions) of different seismic potential, the boundary should be located close to the highest concentration around the hard core of the most active ones; in areas possessing a statistically sufficient number of reliable events, boundaries should be mainly based on seismic data as an expression of tectonic activity and backed up by tectonic arguments. In case of an insufficient number of events or a large number of uncertainties attached to the events, existence of a boundary has been decided by arguments based on the most dominant tectonic or seismic features. In addition to these source zones several background seismicity zones are defined to model the floating earthquakes that are located outside these distinctly defined source zones and to delineate zones where no significant earthquake has taken place.

The source zones defined using all the available data and considering the studies and zonations presented by other researchers are given in figs. 4a-c as, respectively overlain with the neotectonic features and the seismictity. The source zones numbered from 1 to 37 are referred in table I.

Source zones from 28 to 35 in Eastern Turkey were obtained from Sesetyan (1997), and the source zone 25 in the Cyprus region was acquired from Birgoren *et al.* (1997).

Detailed description of the seismicity and the neo-tectonics associated with these source zones will be provided in another publication.

To avoid sudden changes in seismicity at source zone boundaries, SEISRISK III permits an option to account for earthquake location uncertainty. Instead of assuming that source zones are homogeneous, that is each point within a source zone has the same probability of being the epicenter of a future earthquake, the earthquake location uncertainty allows the assumption of each point within a source zone being the mean or most likely location of a future earthquake. A constant location uncertainty of 10 km was adopted for this study.

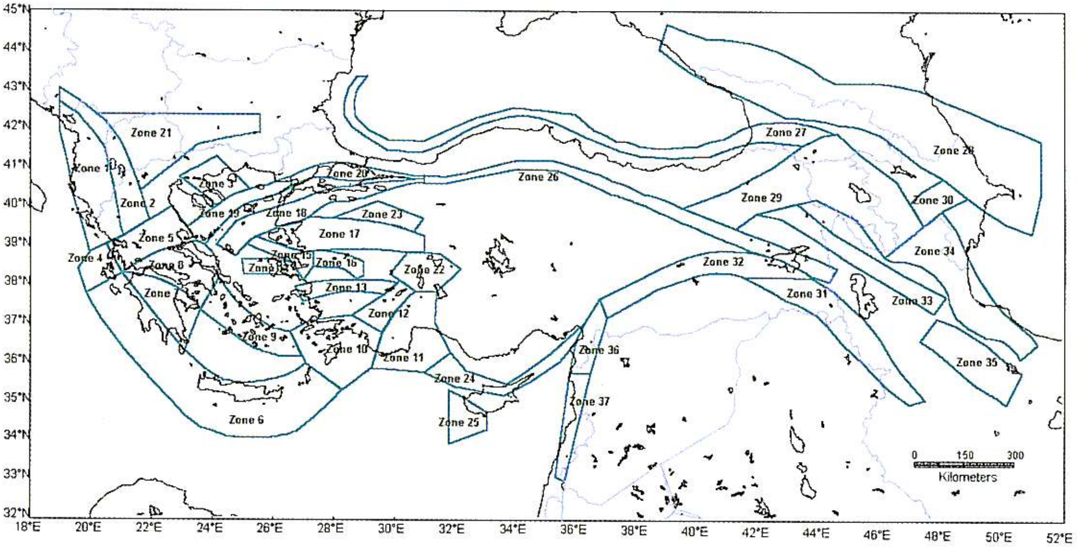

Fig. 4a. Seismic source zones.

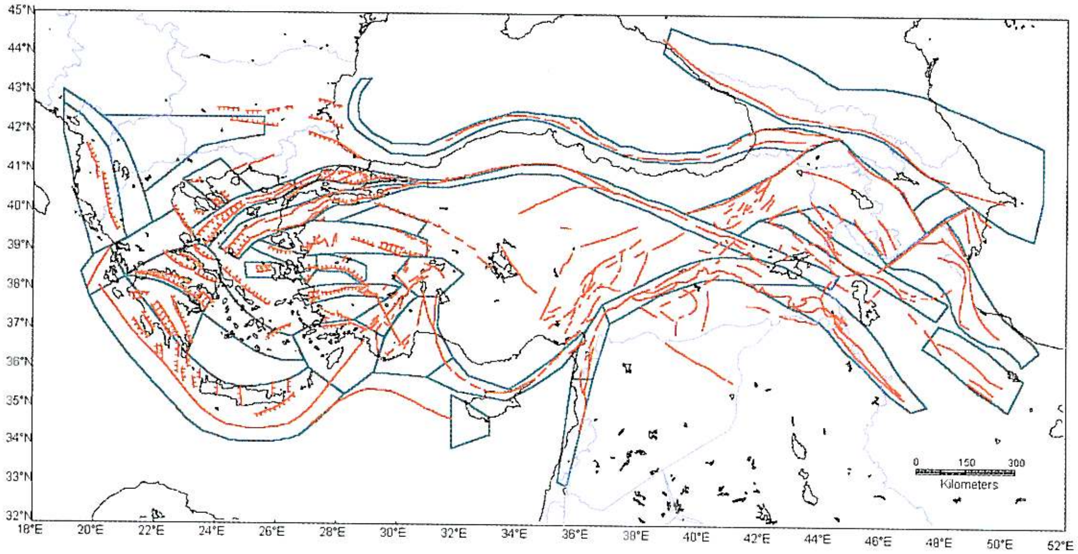

Fig. 4b. Seismic source zones together with the major tectonic features.

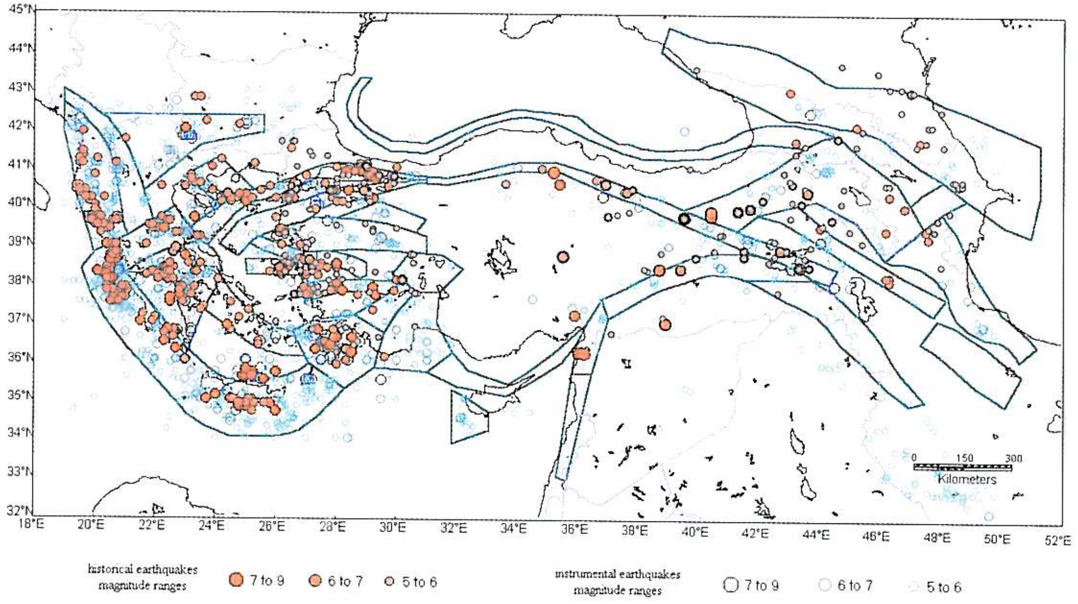

Fig. 4c. Seismic source zones together with the seismicity.

Table I. Source zones, as depicted in fig. 4a.

Zone 1	West Ionian
Zone 2	East Ionian
Zone 3	Chalkidiki
Zone 4	Cephalonia
Zone 5	Central Greece
Zone 6	Cretan arc (Hellenic arc)
Zone 7	Peloponnese
Zone 8	Gulf of Corinth
Zone 9	Cyclades
Zone 10	Fethiye
Zone 11	Antalya
Zone 12	Burdur
Zone 13	Buyuk and Kucuk Menderes
Zone 14	Chios
Zone 15	Izmir
Zone 16	Gediz
Zone 17	Simav
Zone 18	South Strand of the Anatolian trough
Zone 19	Northwest Strand of the Anatolian trough
Zone 20	Northeast Strand of the Anatolian trough
Zone 21	Sreanogorie
Zone 22	Lakes
Zone 23	Kutahya
Zone 24	Cyprus
Zone 25	SW of Cyprus
Zone 26	NAF
Zone 27	Black Sea
Zone 28	Caucasus
Zone 29	Pambak-Sevan
Zone 30	Arax
Zone 31	EAF
Zone 32	Bitlis-Zargos
Zone 33	Tebriz
Zone 34	Talish
Zone 35	Soltanieh-South Parandak
Zone 36	Hatay (Antioch)
Zone 37	Dead Sea

6. Recurrence relationships

The empirical Gut-Richter recurrence relationship for earthquakes:

$$\log N = a + bM \tag{6.1}$$

where N is the number of the earthquakes above the magnitude M in a given region and within a given period and a and b are regression constants, has been extensively used in many seismicity studies and has also been confirmed to hold for micro-earthquakes. The coefficient a is a constant that is dependent on the location and time of the sample used and b represents a constant thought to be characteristic of the region.

The earthquake catalogues are often biased due to incomplete reporting for smaller magnitude earthquakes in earlier periods. Thus to fit the recurrence relationship to a region, one should choose to use: 1) a short sample that is complete in small events, or 2) a longer sample that is complete in larger events, or 3) a combination of the two data sets to complete the deficient data thereby obtaining a homogeneous data set. A direct attempt to fit these data to a regression relationship may result in quadratic or higher order expressions to accomodate the inherent bias and inhomogeneity of the data. In the method used in this study, an artificially homogeneous data set is simulated through the determination of the period over which the data in a given magnitude group are completely reported (Stepp, 1973).

It is known that the use of fault segmentation models, where the magnitude of the characteristic event on each segment is determined using the relations between surface rupture length and moment magnitude, provides a better description of the recurrence rates for North and East Anatolian Faults. We tried to obtain the geologic slip rate and a characteristic magnitude and derive the a-value by requiring the moment rate to equal the annual moment sum of earthquakes. For *a-priori* values of b based on the regional seismicity, the a values were somewhat less than those obtained on the basis of the Stepp (1973) procedure. For the sake of uniformity, less uncertainty and conservation we used the recurrence relationships based on the Gutenberg and Richter model.

As input to the SEISRISK III software we entered the earthquake occurrence rates simulated on the basis of the log-linear least-squares regression analysis of the seismicity data. For all source zones the slope (b-value) of the frequency-magnitude relationship varies between

– 0.7 and – 1.1, with most zones having values around – 0.8. Obviously depending on the size and the seismicity of the source zone considered, *a*-values show a greater variation between 0.5 and 6.

7. Attenuation relationships

Assessment of the seismic hazard requires an appropriate strong-motion attenuation relationship, which depicts the propagation and modification of strong ground motion as a function of earthquake size (magnitude) and the distance between the source and the site of interest. The scarcity of the local strong-motion acceleration data in Turkey makes it unavoidable to either define the attenuation on the basis of local intensities or borrow the already developed acceleration attenuation relationships based on foreign data. Erdik *et al.* (1985) showed that the attenuation relationships based on Western American strong-motion data satisfactorily agree with the strong-motion data obtained from Anatolian earthquakes. For Peak Ground Acceleration (PGA) we used the following attenuation relationships with equal weight.

7.1. *Attenuation relationships developed by Campbell (1997)*

Campbell (1997) developed a set of attenuation relationships to predict free-field horizontal and vertical components of Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), and 5%-damped pseudo-absolute acceleration response spectra (PSA). He used 226 recordings of 30 earthquakes from worldwide active tectonic regions for the horizontal components of spectral acceleration . He restricted the recordings used to near-source distances, in order to minimize the influence of regional differences in crustal attenuation and to avoid the complex propagation effects observed at longer distances during earthquakes. The attenuation relationships are considered to be appropriate for predicting free-field amplitudes of horizontal and vertical components of strong ground motion from worldwide earthquakes of moment magnitude (*M*) greater than or equal to 5 and sites with distances to seismogenic rupture less than or equal to 60 km in active tectonic regions.

7.2. *Attenuation relationships developed by Boore* et al. *(1997)*

Since first publishing their attenuation relationships in 1981, Boore *et al.* (1997) have revised their relationships many times. Boore *et al.* (1997) proposed attenuation relationships for random horizontal peak ground acceleration and pseudo-acceleration response spectra for shallow earthquakes in Western North America. The equations give ground motion in terms of moment magnitude, distance, and site conditions for strike-slip, reverse-slip, or unspecified faulting mechanisms. Site conditions are represented by the shear velocity averaged over the upper 30 m.

7.3. *Attenuation relationships developed by Sadigh* et al. *(1997)*

Sadigh *et al.* (1997) presents attenuation relationships for peak acceleration and response spectral accelerations from shallow earthquakes. The relationships are based on strong motion data primarily from California earthquakes. Relationships are presented for strike-slip and reverse faulting earthquakes, rock and deep soil deposits, earthquakes of moment magnitude *M* 4 to 8+, and distances up to 100 km.

In the SEISRISK III software the attenuation function is input as a table of values of the chosen ground motion parameter as a function of magnitude and distance. The software allows the modeling of acceleration variability. Rather than assuming a single value of acceleration resulting from earthquakes at each magnitude and distance, a range of accelerations lognormally distributed with standard deviation. The Cornell (1968) methodology used in SEISRISK III formulation, computes the hazard at each site of the study region by discrete summation of the individual contributions from the mass center of the elementary cells in source zone considered. It should be noted that, this distance may or may not correspond exactly to the distance definitions used in the above attenuation relationships.

8. Seismic hazard maps: results and discussion

The seismic hazard was computed using the computer code SEISRISK III (Bender and Perkins, 1987), with areal source settings. The final maps were done over a 0.05° × 0.05° grid, for a total number of more than 184 800 computation nodes.

The calculations were performed using three equally weighted attenuation relationships (Campbell, 1997; Boore *et al.*, 1997; Sadigh *et al.*, 1997) for competent or rock sites, sites with shear wave propagation velocity greater that 700 m/s, and with undifferentiated source mechanisms, whichever appropriate and applicable. The log-normal, magnitude-independent standard deviation values associated with these attenuation relationships were utilized in the computations. The use of these three attenuation relationships with equal weights follows that used in Frankel *et al.* (1996) for the Western United States.

In line with the GSHAP standarts, the seismic hazard map in terms of iso-horizontal PGA contours corresponing to 475 year return period (10% probability of exceedance in 50 years) and competent free-field ground (rock site or sites with shear wave propagation velocity greater 700 m/s) is provided in fig. 5.

The following characteristics of these maps should be noted:

– The PGA values denote maximum horizontal accelerations on competent soil. With soil deposits of soft- and medium-stiff sands and clays of appreciable depth the ground accelerations will be different than those indicated on these hazard maps.

– In the delineation of the seismic sources the geological boundaries of the tectonic elements and their immediate vicinity have been

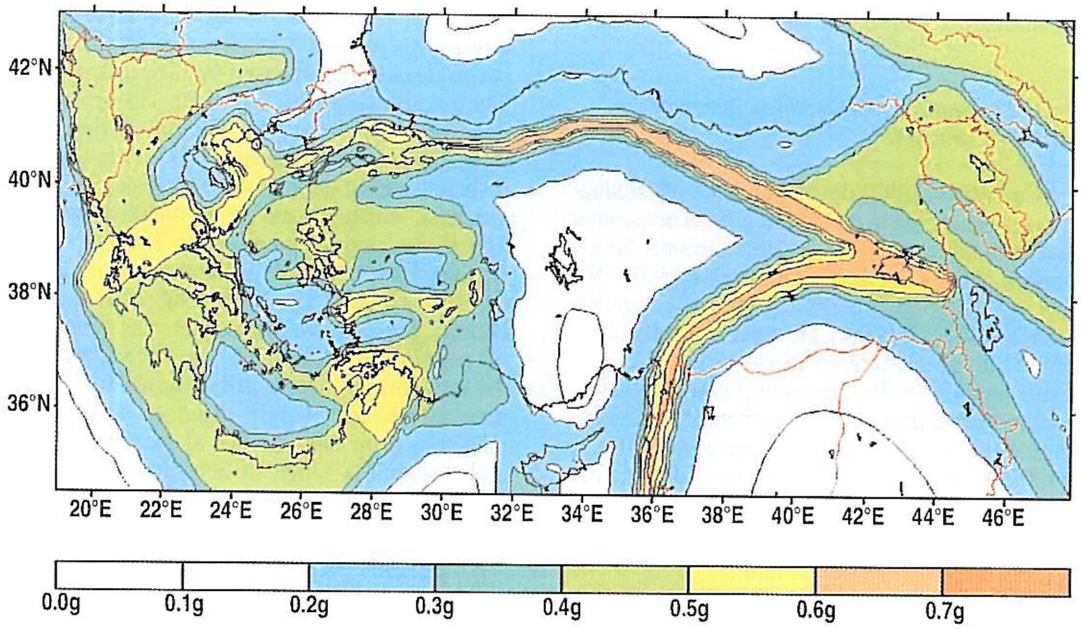

Fig. 5. PGA (*g*) values with 10% probability of exceedance in 50 years.

considered. The seismic hazard near the source boundaries is directly and strongly affected by the changes in the delineation of these boundaries.

– The recurrence relationships used in the preparation of these maps are based on artificially complemented data sets that can account for the small magnitude data deficiencies in earlier reporting periods. The net effect of such a procedure reflects itself in the increase in the slopes of the log-linear recurrence relationships and in the decrease of the relative number of earthquakes at the high magnitude end. The effect of such an approach on the hazard maps can be appreciable for the return period considered.

– In the seismic source regionalization methodology utilized in this map, it was tacitly assumed that in the future the locations of major seismic activity will be essentailly limited to seismic zones, as has been the case over the course of the recorded history. In the past, certain parts of these source zones remained locked for considerable periods of time and this indeed may be the case in future. However, there is no conceivable physical model that can accurately predict the locality and inception and termination times of these locking periods and the best one can do is to be on the conservative side and assume that these seismic sources will remain active in the future.

– Seismic hazard is based on the derived recurrence relationships which represents extrapolations into the future assuming that the rate of the seismic activity observed in the past will essentially repeat itself in the future. Although a decrease in the seismic activity in certain seismotectonic regions can cause an overestimation of the seismic hazard the opposite can not be tolerated and is believed to be accounted.

Acknowledgements

The work reported herein represents a selected sub-section of the graduate studies conducted by Keypour (1992), Sesetyan (1997), Onur (1997), Birgoren *et al.* (1997) and Biro (1999) in the Department of Earthquake Engineering of Bogazici University. A comprehensive report encompassing these studies is in preparation. The assistance of Talhan Biro in resolving several problems with the software needs to be acknowledged. We are grateful for all the assistance rendered by Professor Aykut Barka for allowing us to use his tectonic maps and interpretations and for providing guidance in the delineation of seismic source regions. We also thank Professor Domenico Giardini in encouraging us to write this paper.

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