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Seismic Hazard and Seismic Risk Analysis in Turkey Deduced from Mixed Files

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Abstract: *A probabilistic approach is applied to assess the seismic hazard in Turkey. This methodology allows the use of either historical or instrumental data or a combination of both. It has been developed specifically for the estimation of seismic hazard in a specified area or in a specified site and has the advantage that does not require any specification of seismic zones. A relation for the attenuation of peak ground acceleration of shallow seismicity in Turkey was employed. The area was divided in grid of* 0.25^o *X* $0\ 25^o$ *and the seismic hazard map constructed for Turkey specifies a 10% probability of exceedance of a given peak ground acceleration (PGA) values for an exposure of 50 years. The map corresponds well with the tectonic features (North and East Anatolian Fault) of the examined area where the largest values are estimated.*

Moreover an effort is made to evaluate the seismic risk in Turkey considering the information provided by the seismological institutes of the country. Such information concerns the damages caused by large earthquakes ($M \geq 5.5$*) during the* 20^{th} *century on the buildings, as well as the human victims. It is observed that the most murderous earthquakes was the one of 1939 in Erzincan with magnitude M=7.9 caused about 33.000 deaths and the second was the well-known event of 1999 in Izmit with magnitude M=7.4 caused more than 15.000 deaths.*

Keywords: *Seismic Hazard, Seismic Risk, Probabilistic Approach, Turkey.*

INTRODUCTION AND DATA USED

Numerous studies of local or regional scale (Alsan, 1972; Gencoglu and Tabban, 1973; Bath, 1979, among others) have addressed the problem of assessment of seismic hazard in Turkey using the statistical processing of the instrumental earthquake data. More comprehensive studies on the subject matter have been conducted by Yarar et al. (1980), Erdik and Oner (1982), Erdik et al. (1985) and Gulkan et al. (1993).

Although reports are known (Kayabali and Akin, 2003) that the Turkish instrumental records are far from being incomplete for probabilistic approach of seismic hazard, an effort is undertaken for such analysis. For this reason a procedure called “parametric-historical” introduced by Kijko and Graham (1998, 1999) is adopted. The procedure does not require any specification of seismic zones and allows for the use of the whole seismological record, comprising both historical and instrumental data, available for the region of interest. Moreover the consideration of different detection thresholds and the incorporation of magnitude uncertainty, are estimated through the adopted procedure. Recently, Jiménez et al. (2001) presented a unified seismic hazard modeling throughout the whole Mediterranean area. The whole area is subdivided into seismic source zones which are established according to tectonic, geophysical, geological and seismological data. A uniform seismic behavior is assumed for each zone, the magnitude-frequency parameters and the maximum expected magnitude are determined on the basis of the seismic catalogue, and finally the expected ground motion is computed through an appropriate attenuation relationship.

The data set used with magnitudes $M \geq 4.5$ for the purpose of the present study is extracted from the Kandili observatory and covers the time period 1900-2000. A set of historical data is provided by British Geological Survey (Musson, personal communication). For the purpose of the study, the attenuation law found in the paper of Kayabali and Akin (2003) but proposed by Sadigh et al. (1997) is applied. For the whole Turkey the parameters of the magnitude-frequency relationship are $a=5.16 \pm 0.12$ and $b=-0.88 \pm 0.02$, while the maximum observed magnitude is 7.9 for the instrumental period, but in the historical part of the data set the largest shock with magnitude 7.7 occurred during 1509 in Marmara Sea (40.92°N-28.74°E). A very useful catalog which includes a lot of information (year of occurrence, magnitude, intensity, number of deaths, damaged buildings, etc.) for the strong and catastrophic ($M \geq 5.5$) earthquakes, during 20th century, in Turkey, is also available and is used for the purpose of the assessment of seismic risk.

ASPECTS OF THE METHODOLOGY

According to Reiter (1990) there are three definitions of the maximum magnitude in common use in contemporary seismic hazard analysis: a) the maximum regional earthquake is the maximum (possible) earthquake that could occur in a given time interval and tectonic regime and it defines an upper bound to earthquake size determined by earthquake processes. This is primarily used in probabilistic analyses; b) the maximum credible magnitude is commonly estimated in deterministic analyses and it defines a reasonable assessment of maximum earthquake potential in light of current tectonics, and c) the maximum historic earthquake is the maximum earthquake associated with a seismotectonic source of historical or instrumental evidence. The estimation of the maximum regional (possible) earthquake is of the subjects of the present work.

The method used to estimate the level of seismic hazard in terms of PGA has been described in details in (Kijko and Graham, 1998, 1999). The first part of their work focussed on the development and presentation of statistical techniques that can be used for the evaluation of the maximum regional magnitude M_{max}. The second part delineates the methodology for probabilistic seismic hazard assessment at a given site. In the present study, emphasis is given on the latter aspect.

Site-specific analyses of seismic hazard require knowledge of the attenuation of the selected ground-motion parameter *α*, usually PGA, as a function of distance. According to the adopted methodology, the general form of the attenuation law of PGA is assumed to be of type:

$$\ell n(a) = c_1 + c_2 m + \phi(r) + \varepsilon \quad (1)$$

where c_1 and c_2 denote empirical coefficients, m is the earthquake magnitude, $\phi(r)$ is a function of earthquake distance and ε is a normally distributed random error.

In order to express seismic hazard in terms of PGA, the aim would be to calculate the conditional probability that an earthquake of random magnitude occurring in random distance from the site will cause a PGA value equal to, or greater than, the chosen threshold value, $\alpha_{\min}$, at the site. We accept the standard assumption (e.g. Page, 1968) that the random earthquake magnitude *m*, in the range of $m_{min} \le m \le m_{max}$, is distributed according to the doubly truncated Gutenberg-Richter relation with a cumulative distribution function (CDF):

$$F_M(m) = \frac{\exp(-\beta m_{\min}) - \exp(-\beta m)}{\exp(-\beta m_{\min}) - \exp(-\beta m_{\max})}. \quad (2)$$

In equation (2), $m_{\min}$ is the minimum earthquake magnitude corresponding to α_{min}, which is the minimum value of PGA of engineering interest, $m_{\max}$ is the maximum credible earthquake magnitude and $\beta = b.ln(10)$, where b is the known parameter of the Gutenberg-Richter magnitude-frequency relation. It has been shown by Kijko and Graham (1999) that choosing equation (1) as a model for attenuation of PGA and equation (2) as a distribution of earthquake magnitude, is equivalent to the assumption that the CDF of the logarithm of PGA, *x*, is of the form:

$$F_x(x) = \frac{\exp(-\gamma x_{\min}) - \exp(-\gamma x)}{\exp(-\gamma x_{\min}) - \exp(-\gamma x_{\max})}. \quad (3)$$

Above, $x_{\min} = \ell n(a_{\min})$, $x_{\max} = \ell n(a_{\max})$, $a_{\max}$ is the maximum possible PGA at the site, $\gamma = \beta/c_2$ where c_2 is the coefficient related to the attenuation formula (1) and β is the parameter of the Gutenberg-Richter distribution of earthquake magnitude. It can be seen from formula (3) that the logarithm of the PGA at a given site follows the type of distribution as the earthquake magnitude, i.e. doubly truncated negative exponential the form Gutenberg-Richter distribution in equation (2). The two distributions differ only in the value of their parameters. If parameter of the magnitude distribution is equal to β, the parameter of the distribution of $x = \ell n(PGA)$ is equal to β/c_2.

From an engineering point of view, the largest PGA expected at least once at a given site during a given time interval, *t*, is of special interest. The CDF of the logarithm of the largest PGA value, *x*, observed at least once at the site during a specified time interval *t*, can be written as:

$$F_x^{\max}(x \mid t) = \frac{\exp\{-\lambda t[1 - F_x(x)]\} - epx(-\lambda t)}{1 - \exp(-\lambda t)} \quad (4)$$

where λ is the site-specific activity rate of earthquakes that cause a PGA value, *α*, at a site, exceeding the threshold value $a_{\min}$. Clearly, this CDF of the largest PGA values is doubly truncated: from below by $x_{\min} = \ell n(a_{\min})$ and from above, by $x_{\max} = \ell n(a_{\max})$. The distribution in equation (4) was derived under the assumption that the earthquakes that cause a PGA value α, $a \geq a_{\min}$, at the site, follow the Poisson process with mean activity rate $\lambda(x) = \lambda - [1 - F_x(x)]$, with $x = \ell n(a)$.

The maximum likelihood method is used to estimate the site-characteristic seismic hazard parameters λ and γ. If $a_1,...,a_n$ are the largest PGA values recorded at the site during n successive time intervals $t_1,...,t_n$ the likelihood function of the sample $x_1,...,x_n$, where $x_i = \ell n(a_i)$ and $i = 1,...,n$, for a specified value $a_{\max}$ can be written as:

$$L(\lambda, \gamma) = \prod_{i=1}^{n} f_x^{\max}(x_i \mid t_i) \tag{5}$$

where $f_x^{\max}(x_i \mid t_i)$ is the probability density function of the logarithm of the largest PGA value observed at a given site during a given time interval t. By definition, the probability density function is

$$f_X^{\max}(x_i \mid t_i) = \frac{dF_X^{\max}(x_i \mid t_i)}{dx}.$$

For a given value of x_{max} (or equivalently, the maximum possible PGA at the site), maximization of the likelihood function (5) leads to the determination of the parameters λ and γ. In order to create seismic hazard maps, the procedure can be repeatedly applied to grid points covering the area of interest.

The method allows for the utilization of all available seismicity information, as it makes use of an earthquake catalogue containing both incomplete historical observations and more congruous and complete instrumental data. In addition, the procedure accepts division of the complete part into subcomplete catalogues, each being complete starting from its own level of completeness. Periods with no entries in the catalogue can also be taken into account.

SEISMIC HAZARD MAP

From computational point of view the procedure involves the area-specific and the site-specific parts. Firstly the parameters the maximum magnitude M_{max}, average seismic activity rate λ, and the b-value of Gutenberg –Richter magnitude frequency relation (or β=bln10) are calculated from an area surrounding the site for which seismic hazard analysis is needed. The three parameters are determined simultaneously using an iterative scheme. The estimation of λ and β assumes the validity of a Poisson distribution of earthquake occurrence with activity rate λ and the doubly truncated Gutenberg - Richter relationship. Estimation of these parameters also employs the maximum likelihood method. The maximum magnitude M_{max} can be evaluated following different parametric procedure, when both the analytical form and the parameters of the distribution functions of earthquakes magnitude are specified (Kijko and Graham, 1998).

The site-specific computations require knowledge of the attenuation of the selected ground-motion parameter, α, as a function of distance. In this work, the attenuation law for Turkey found in the paper of Kayabali and Akin (2003) but proposed by Sadigh et al. (1997), is applied as aforementioned. For every grid mesh point of 0.25° a radius of 50 km around is adopted in order to collect all the earthquakes and estimate then through the attenuation law the PGA value for this point. In this way we scanned the whole country and produced a probabilistic seismic hazard map (Fig.1).

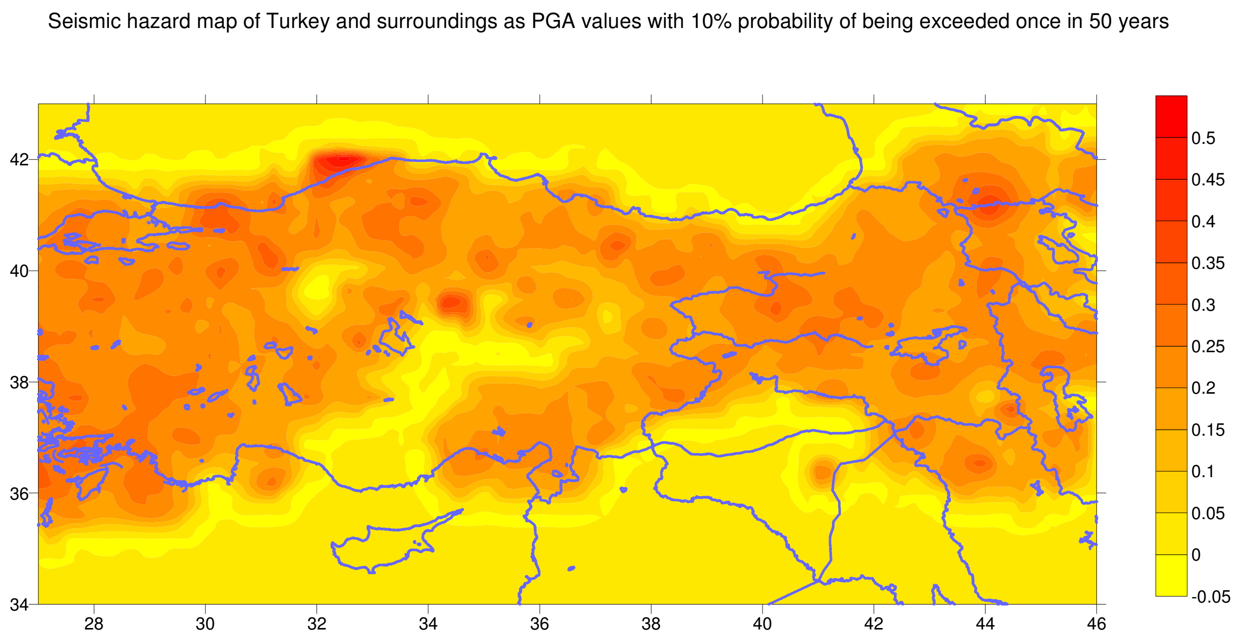

Fig. 1. – Seismic hazard map of Turkey and surroundings

A first inspection on seismic hazard map (Fig. 1) shows a good correlation between the hazard values and the main tectonic features of the broad area (see for details in Kayabali and Akin, 2003, Fig. 5). In details high values are observed along the North Anatolian Fault and East Anatolian Fault. In the western part of Turkey a number of faults are observed perpendicular to the coasts of Anatolia. Most of the highest values observed in this part of the country although the dominant values ranged between 0.25-0.35 g. The obtained results are in good agreement with the map compiled for the whole Mediterranean and its surroundings by Jiménez et al. (2001). Although they used another computer code (SEISRISK III) where the definition of the seismic zones is necessary, the seismic hazard trends of both maps (Fig. 1 and the one of Jiménez et al.) are very comparable, illustrating the PGA values with 10% probability of exceedance in 50 years.

SEISMIC RISK

It is wide known that active tectonics in Turkey are manifested by high seismic activity along North and East Anatolian strike-slip faults. Descriptions as well as observations declare the heavy damages caused by strong earthquakes in Anatolia and south-east Turkey.

Expected earthquake losses are approached by the assessment of seismic risk which is a description of the measurable impact of the earthquakes on the human society. The seismic risk is estimated by the damage in the technical structures and the consequence of earthquakes on national cultural heritage, economy, etc. A measure of seismic risk can be considered the number of deaths caused by earthquakes. In Figure 2, we plot the epicenters of the known murderous earthquakes in Turkey since 1900, according to the catalogue distributed by Kandilli observatory which includes all strong and catastrophic ($M \geq 5.5$) shocks. We observe that the most of them occurred in the North Anatolian Fault, and less seems to occur in the part of the East Anatolian Fault.

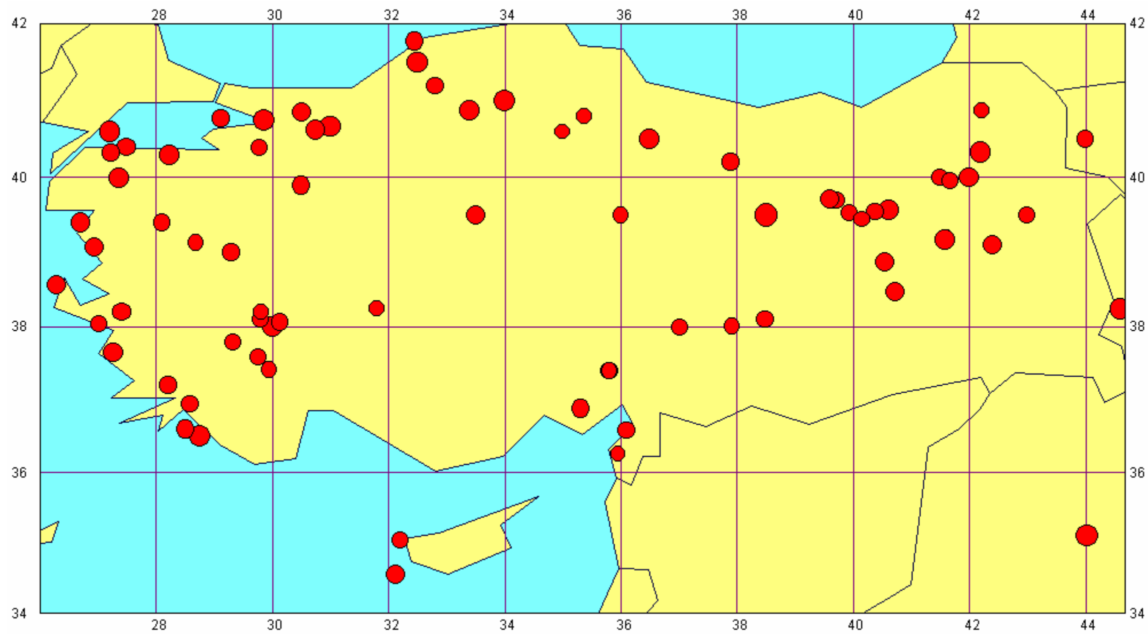

FIG. 2. The places of the most murderous earthquakes in Turkey and the surrounding area during the 20th century

In Figure 3, we plot the number of killed people during the 20th century in Turkey. We want to notice that in this figure only the events caused 10 or more kills are applied. A first inspection in Figure 3 reveals that the most deaths caused mainly by two shocks. The one of 1939 with magnitude M=7.9 and intensity $I \geq X$ in Erzincan and the second generated in 1999 with magnitude M=7.4 and intensity I=X in Izmit, Marmara. One more conclusion derived from Figure 3 is that the 64.2% of the losses happened during the first 50 years of the 20th century, while the rest 35.8% is observed during the second half of the examined century. This may depend on two reasons. The first one is that the most murderous earthquake occurred during the first half of the 20th century, and second is that during the last 50 years many improvements on the technical structures are applied.

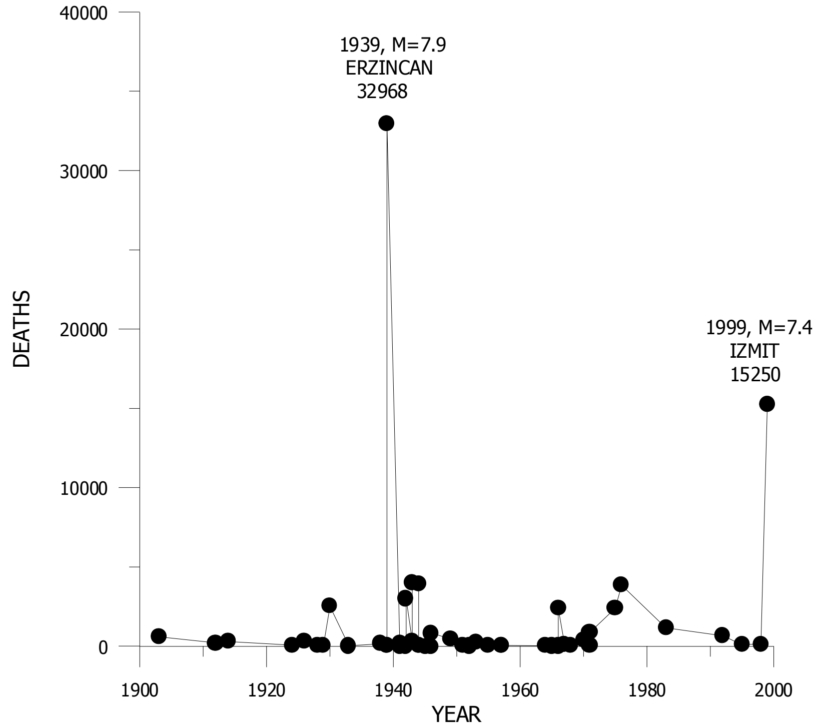

FIG. 3. The most murderous earthquakes in Turkey during the 20th century. Only the events caused 10 or more kills are depicted.

Figure 4 is another interesting plot which represents the seismic risk in Turkey. We can conclude from this plot that the number of human losses (except the events of 1939 and 1999) are less than 4000 (this peak observed during the earthquake of 1943 with 7.2, in Ladik-Samsun). The plot also illustrates the number of deaths during corresponding shocks which have caused intensity $I \geq VII$ (except the extremes of Erzincan and Izmit). It is obvious that the large earthquakes caused almost significant number of victims in the studied area, either they occurred in the first half of the 20th century or they are more recently events.

We considered the number of damaged buildings as another expression of seismic risk. We observed that, in the available catalogue, there were events during the studied period that caused damages without victims or vice versa. In order to include both measure parameters of seismic risk, we considered the ratio **(r)** of deaths to damaged buildings as a measure of seismic risk and we believe that it is more reliable because it includes also measures of seismic risk. In Figure 5, we plot the ratio **(r)** versus the intensity. We noticed that earthquakes with zero number of damages or without victims are excluded from this plot. We also supposed the data set (used for plotting in Fig. 5) as homogeneous one. (e.g. the population of the area is constant during the year seasons, summer, winter, etc.).

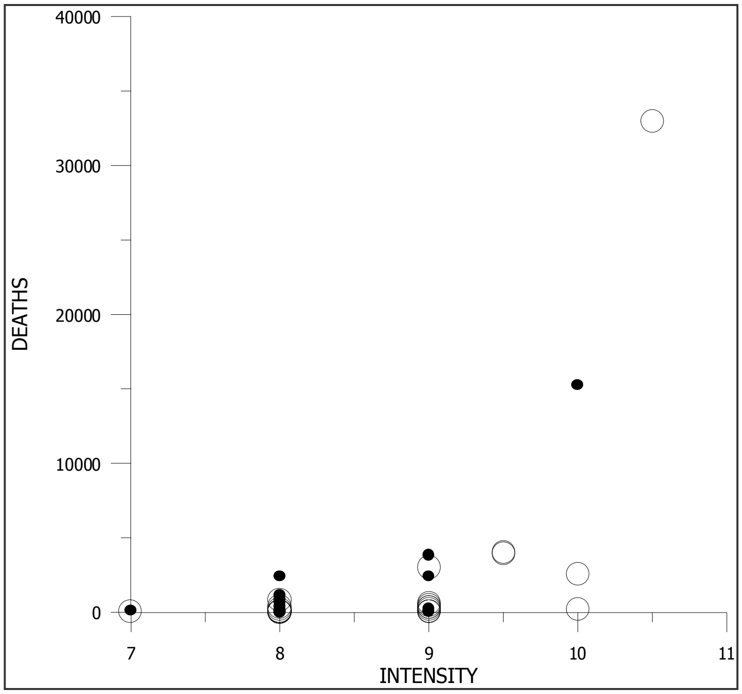

FIG. 4. Plot of the number of deaths versus intensity. Open circles show data between the time interval 1900-1949, while black circles depicts the time period 1950-1999.

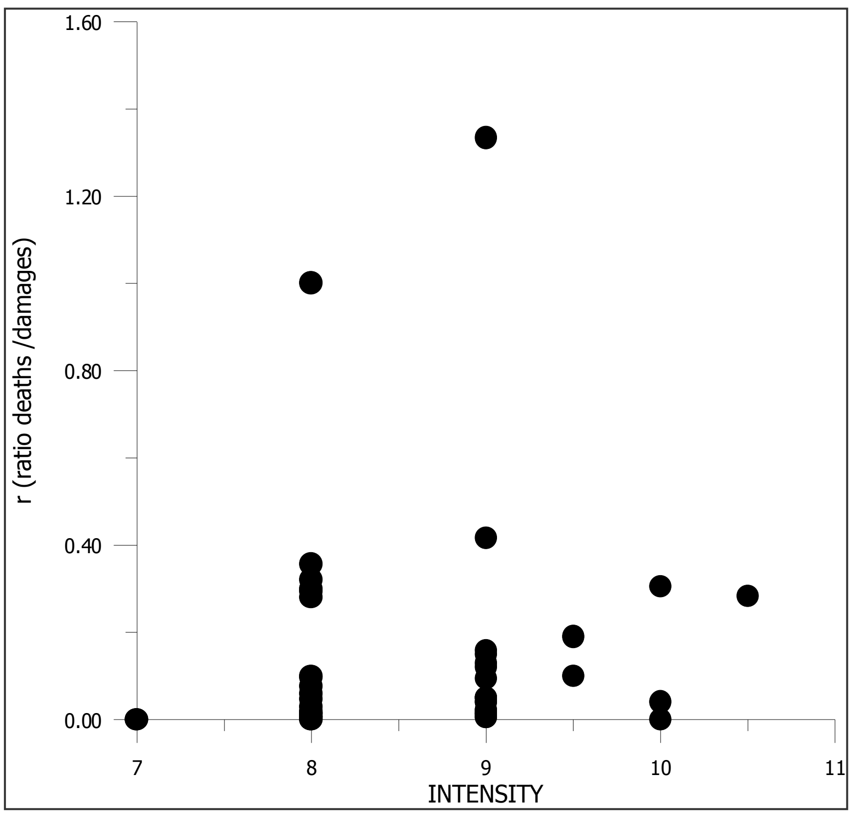

FIG. 5. Plot of ratio (**r**) of deaths to damaged buildings against the intensity. Data without victims or damages are excluded.

CONCLUSIONS

An effort is made for estimating a probabilistic seismic hazard in the area of Turkey. The applied method (Kijko and Graham, 1998,1999) has the advantage that it does not require any specification of seismic zones and allows for the use of all the available data for the region under investigation either they are historical or instrumental records. The obtained outputs are very comparable with the results of other methods previously applied in the area. The seismic hazard values are in good agreement with the main tectonic features of Turkey.

A study is undertaken to assess the seismic risk in Turkey. We conclude that in Turkey murderous events occurred. The two most known are: 1) the shock of 1939 with M=7.9 in Erzincan which kills almost 33.000 people and 2) the event of 1999 with M=7.4 in Izmit which kills about 15.000 people. The losses of all the other shocks are less than 4.000 people which is a large number of kills, as well. We also conclude that the shocks with intensity I≥VII caused a significant number of victims A new measure which includes both seismic risk parameters, victims and the number of damaged buildings, introduced. The ratio **r** was plotted versus intensity and reveals that almost high **r** values exceeded intensity VII. For the first half of the 20th century the ratio r=5.1 kills/damaged building, while for the second half r=2.6 kills/damaged building. Because of the reduction in the ratio, we can conclude that some more investigations was taken into account to the seismic codes in order to make the ratio to be lower than the mean of the country which is 3.7 kills/damaged building. The obtained results considered when both quantities are greater than zero. This means that if kills are zero or damages are zero we do not determined the ratio. We also put another condition which is that the data should be homogeneous. This means that the population of an area is almost stable at least during the year of the earthquake occurrence.

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