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Abstract

Stochastic methods are utilized for the assessment of seismic hazard for the Eskisehir region. A comprehensive earthquake catalog, in which earthquakes in different scales are converted to a common scale, is compiled. Seismic source zones near the region with revised boundaries and various attenuation relationships are employed. Uncertainties related to the seismicity parameters and different assumptions are taken into consideration by using the logic tree procedure. Seismic hazard maps in terms of peak ground acceleration and MSK intensity, corresponding to a return period of 475 years are developed for Eskisehir. At the end of the study, the expected earthquake damage is estimated for the 31 districts located in Odunpazari, which is a municipality of Eskisehir.

Introduction

In this study, a probabilistic seismic loss estimation methodology is applied for the assessment of potential earthquake losses in a certain municipality of Eskisehir, as a part of an ongoing research entitled: "An Integrated Natural Disaster Risk Assessment Model for Urban Areas for Sustainable Development: Earthquake Case". According to the current seismic zoning map of Turkey, the city of Eskisehir is located in Zones II to IV. Eskisehir is one of the important centers of industry in Turkey. A number of dams and two universities are located within the city boundaries. Due to its rapid development, Eskisehir has become a popular location for new investments.

The basic steps of the methodology are seismic hazard analysis, vulnerability analysis and loss estimation. In the following sections these steps are briefly described and applied for the assessment of seismic hazard for the city of Eskisehir and the estimation of the expected earthquake damage for the 31 districts located in Odunpazari, which is selected as the region for the pilot study.

Probabilistic Seismic Hazard Analysis

Since earthquakes exhibit randomness with respect to time of occurrence, magnitude and location, seismic hazard analysis should be performed in a probabilistic manner. The basic steps of seismic hazard analysis are the delineation of seismic sources, assessment of the earthquake occurrence characteristics for each seismic source, selection of the appropriate ground motion prediction equation and identification of the site characteristics. The aleatory and epistemic uncertainties involved in these steps can only be taken into consideration by using the probabilistic methods.

The Earthquake Data Base and the Modifications. Earthquake catalogs are the most important sources of information in forming the seismic data base to be used in seismic hazard analysis. However, the information presented in the catalogs cannot be used directly and has to be processed. Generally, earthquake magnitudes are reported in different magnitude scales and it is desirable to form a unified catalog by converting the different magnitude scales into a single one. The implementation of the Poisson model requires the elimination of the spatial and temporal dependencies created by fore and aftershocks. Another problem is the fact that earthquake catalogs are often biased due to incomplete reporting for small magnitude earthquakes as well as for the large magnitude earthquakes having long return periods. In performing the seismic hazard analysis for Eskisehir these problems are handled as follows:

A comprehensive seismic data base, which contains the earthquakes that have occurred within 250 kms of the city center (coordinates: 30.489˚ E longitude and 39.774˚ N latitude) in the last century is compiled. It is assumed that the seismic hazard for the Eskisehir region is due to the seismic activity occurring in a rectangular region bounded between 27.50˚–33.50° E longitudes and 37.50˚–42.00° N latitudes. In preparing this seismic data base, four different sources of seismicity data were utilized. These are the catalogs provided by the Earthquake Research Department of General Directorate of Disaster Affairs of Turkey (GDDA-ERD), Kandilli Observatory and Earthquake Research Institute of the Bogazici University (KOERI), International Seismological Centre (ISC) and United States Geological Survey (USGS). The data in these catalogs were provided in different magnitude scales and it is necessary that they are converted to a single scale. All the magnitude scales used in the seismic data base are homogenized and converted to the moment magnitude scale. The moment magnitude (M_w) scale is selected since in recent years this scale has become the most preferred one. The minimum value of M_w is set to 4.5 and earthquake magnitudes reported in different scales, namely, surface wave magnitude, M_S, local magnitude, M_L, body wave magnitude, M_b and duration magnitude, M_d are all converted to M_w by using the empirical equations that were developed by Deniz (2006). These equations were obtained by applying the orthogonal regression procedure to earthquakes that have occurred in the last 100 years in Turkey.

In order to satisfy the assumptions of the Poisson process it is necessary that earthquake clusters should be identified and dependent events (fore and after shocks) be eliminated from the seismic data base. This is achieved by using the space and time windows specified by Deniz (2006) which were obtained based on an extensive literature survey. The incompleteness in the earthquake catalogs is also taken into account. For this purpose an analysis of catalog completeness is performed and artificially completed rates (i.e. complete number of events over a particular time period) are obtained based on the method proposed by Stepp (1973).

Delineation of the Seismic Source Zones. Since the delineation of seismic source zones depends highly on subjective judgment of experts, the number and the layout of seismic source zones change from study to study. In our study, the configuration given by Bommer, et al. (2002) is adopted with some local modifications (Kocyigit, 2005) to take into account the recent findings. The resulting seismic source zones, which formed the basis for the seismic hazard analysis conducted in this study, are tabulated in Table 1. In the same table the maximum earthquake magnitudes are also given. For the earthquakes that can not be related to any of the 13 seismogenic provinces, background seismicity regions are defined. There exist background seismicity regions both inside and outside of the main seismic source zones listed in Table 1. The configuration of seismic source zones is displayed in Figure 1.

Table 1. Seismic Source Zones and the Expected Maximum Earthquake Magnitude Values Used in the Study

Number	Seismic source zone	$(M_w)_{max}$
1	North Anatolian Fault System- Segment B	8.0
2	North Anatolian Fault System- Segment C	7.4
3	North Anatolian Fault System- Segment D	8.0
4	Bartin Fault Zone	6.8
5	Beypazari-Urus Fault Zone	5.4
6	Orta (Dodurga) Fault Zone	6.2
7	Inonu-Eskisehir Fault Zone	7.1
8	Tuz Golu Fault Zone	6.9
9	Kutahya Fault Zone	6.9
10	Simav-Aksehir Fault Zone	7.2
11	Alasehir-Izmir (Gediz) Graben	7.2
12	Buyuk Menderes Graben	7.1
13	Cameli-Burdur Fault Zone	7.1
G1	Background North	5.8
G2	Background Inner 1	5.4
G3	Background Inner 2	5.4
G4	Background Inner 3	5.4

The earthquakes in the finalized seismic data base are distributed to these 13 main and 4 background seismic source zones according to the location of their epicenters and are used to predict the seismicity parameters of each seismic source zone. For the estimation of the parameters of the linear magnitude-recurrence relationship (mainly β, the parameter of the exponential magnitude distribution) the least squares regression and maximum likelihood methods are applied both to the original (incomplete) and artificially completed data sets, creating four different combinations.

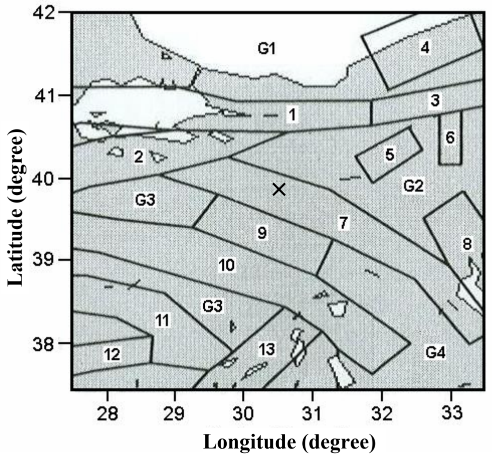


Figure 1. Configuration of the seismic source zones listed in Table 1 (×: Shows approximately the location of Eskisehir's city center).

Attenuation Relationships. Peak ground acceleration and MSK intensity are selected as the earthquake severity parameters. In order to estimate earthquake hazard in terms of these parameters, the following attenuation relationships are employed. For the peak ground acceleration the ground motion prediction equations given by Gulkan and Kalkan (2002) and Boore, et al. (1997) for rock sites are adopted. These equations are, respectively, as follows:

$$\ln Y = -0.682 + 0.253\times(M-6) + 0.036\times(M-6)^2 - 0.562\times\ln r + 0.202 \quad (1)$$

$$\ln Y = -0.242 + 0.527\times(M-6) - 0.778\times\ln r + 0.301 \quad (2)$$

where: $r = \sqrt{r_{cl}^2 + h^2}$; Y = horizontal component of the peak ground acceleration (PGA) in g; M = moment magnitude; r_{cl} = the closest horizontal distance to the vertical projection of the rupture in km; h = fictitious depth, computed by regression analysis as 4.48 km and 5.57 km, respectively for Eqs.1 and 2. The standard deviation, $\sigma_{\ln Y}$ is reported as 0.562 and 0.520, respectively for Eqs. 1 and 2. For intensity attenuation, the following equation proposed by Musson (2000) is used:

$$I = 1.063 + 1.522\times M_s - 1.102\times\ln R - 0.0043\times R \quad (3)$$

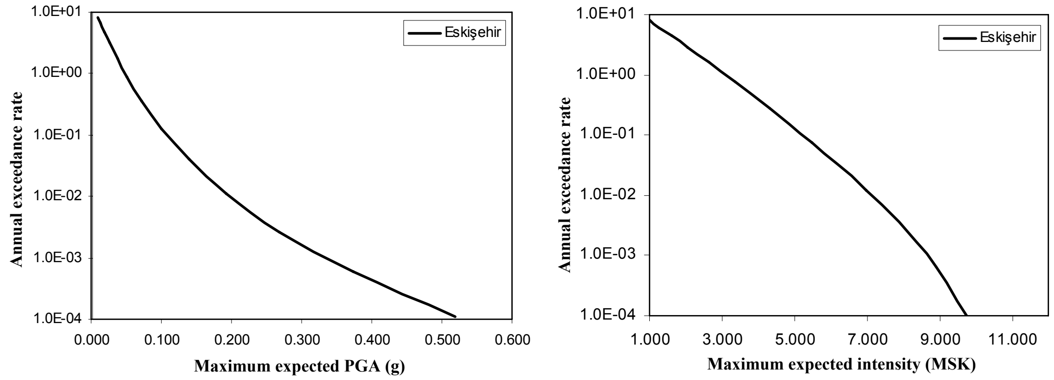
where: I = intensity in MSK scale; M_s = earthquake magnitude in the surface magnitude scale; R = hypocentral distance in kms. The standard deviation came out to be $\sigma_I = 0.486$ (or $\sigma_{\ln I} \approx 0.06$).

Best Estimate of Seismic Hazard for Eskisehir

In order to reflect the influence of various assumptions discussed above and to account for the epistemic uncertainties in the values of seismicity parameters, the logic tree procedure is applied as described below. The alternative assumptions are listed in Table 2, together with the subjective probabilities assigned to them. These probabilities quantify the likelihood of each assumption being valid as compared to the alternative assumptions. Seismic hazard computations are carried out for each one of the resulting 2^4x3 = 48 combinations, considering PGA only. By multiplying the seismic hazard results computed for each one of the 48 combinations by the corresponding joint probability (multiplication of the probabilities of the selected alternatives) of that combination and adding these values, a weighted average seismic hazard value is computed. The resulting seismic hazard curve in terms of PGA is called as the "best estimate" of seismic hazard for Eskisehir and is shown in Figure 2a. The same procedure is repeated for the 48 combinations resulted for MSK and the "best estimate" seismic hazard curve in terms of MSK is obtained as shown in Figure 2b. Based on these "best estimate" hazard curves and for a return period of 475 years the PGA and MSK values are obtained as 0.28g and 8.2 (MSK), respectively, for the city center of Eskisehir.

Table 2. Alternative Assumptions and Corresponding Subjective Probabilities

	Alternative assumptions	Subjective probability
	All earthquakes	0.5
	Main shocks only	0.5
	Incomplete catalogs	0.4
	Artificially completed catalogs	0.6
	Standard least squares regression in the computation of the recurrence relationships	0.4
	Maximum likelihood method in the computation of the recurrence relationships	0.6
If PGA is used	Attenuation relationship of Gulkan and Kalkan (2002)	0.6
	Attenuation relationship of Boore, et al. (1997)	0.4
	Attenuation uncertainty, $\sigma_{\ln Y}$= 0.447	0.1
	Attenuation uncertainty $\sigma_{\ln Y}$ is equal to the reported value	0.6
	Attenuation uncertainty, $\sigma_{\ln Y}$= 0.707	0.3
If intensity (MSK) is used	Attenuation relationship of Musson (2000) in its original form	0.5
	Attenuation relationship of Musson (2000) converted to M_w scale	0.5
	Attenuation uncertainty, $\sigma_{\ln I}$ = 0.01	0.15
	Attenuation uncertainty, $\sigma_{\ln I}$ = 0.06	0.60
	Attenuation uncertainty, $\sigma_{\ln I}$ = 0.10	0.25



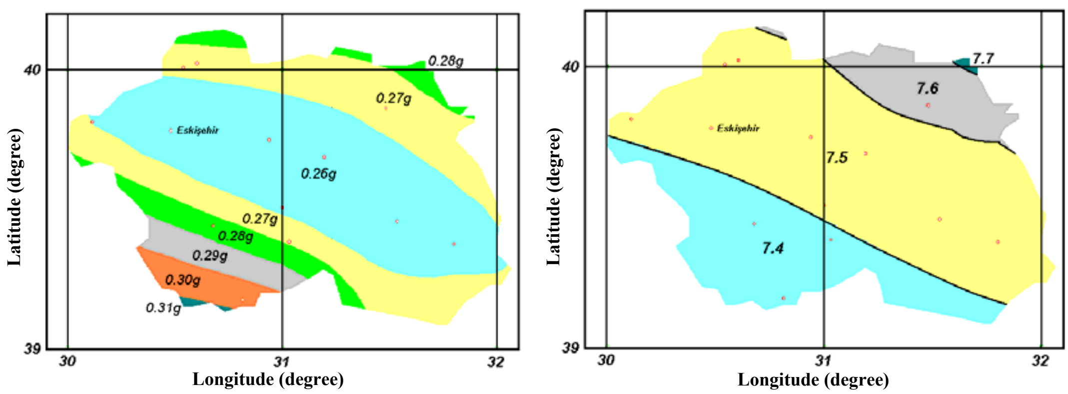
(a) **(b)**

Figure 2. Best estimate seismic hazard curves for Eskisehir/City Center **(a)** In terms of peak ground acceleration (g); **(b)** In terms of intensity (MSK).

Seismic hazard maps are also plotted for peak ground acceleration (PGA) and intensity (MSK) corresponding to a return period of 475 years (10% probability of exceedance in 50 years) considering the combination composed of the most likely assumptions. These maps are shown in Figure 3. All of the seismic hazard calculations are carried out by using the software CRISIS2003 (Ordaz et al., 2003).

Vulnerability Analysis for Odunpazari

According to the seismic hazard map given in Figure 3b, the MSK intensity for a return period of 475 years is about 7.5 for Odunpazari. In other words, from a probabilistic point of view, "moderate" building damage is expected in Odunpazari according to this level of hazard. In order to distinguish the level of damage for the 31 districts located in Odunpazari, it is decided to have a finer classification within the range of moderate damage. For this purpose a more detailed damage analysis is carried out by taking into consideration the characteristics of buildings located in these districts and their distances to the most critical faults in the region.



(a) **(b)**

Figure 3. Seismic hazard maps corresponding to a return period of 475 years obtained based on the combination of the most likely assumptions. **(a)** In terms of peak ground acceleration (g); **(b)** In terms of intensity (MSK).

Servi (2004), has compiled a data base for the 27904 buildings located in the 31 districts of the Odunpazari municipality. This data base contains information on the location (longitude and latitude), number of floors, soil classification (Z1, Z2, Z3, Z4), condition (very bad, bad, moderate, good) and type (reinforced concrete, masonry, wooden) of these buildings.

Seismic Risk Analysis Software (SRAS) prepared by Kucukcoban (2004) is used in order to assess the expected damage in these buildings due to a scenario earthquake. Based on the past seismic activity and the seismic sources delineated in the region, it appears that the most significant seismic threat to Odunpazari is due to the Eskisehir Fault Zone. The 6.4 magnitude of the February 20, 1956 Eskisehir earthquake is taken as the magnitude of the scenario earthquake to be created by this fault. The attenuation equation of Gulkan and Kalkan (2002) given in Eq. 1 is used.

The damage ratios (DR) obtained from the SRAS program for each building is used to find the mean damage ratios (MDR) for each district. Damage ratio is defined as the ratio of the cost of repair of earthquake damage to the replacement cost of the building. The MDR's vary between 23.06 % and 36.48 % for the districts. The variation for the individual buildings is between 21 % and 37 %. In earthquake damage evaluation, generally damage ratios between 10 % to 50 % are rated as moderate damage. Accordingly, all of the districts of Odunpazari are expected to experience moderate damage according to this scenario earthquake. This result is also consistent with the results of the probabilistic seismic hazard analysis conducted for the Eskisehir region as described in the previous sections. However, in order to distinguish the districts according to the expected mean damage ratio, a finer subdivision is established as follows: The districts with MDR less than 25 % are classified as "Light", those with MDR between 25 % and 28 % as "Light-moderate" and those with MDR > 28 % as "Moderate". The indicator variables 0 (zero), 1 (one) and 2 (two) are assigned, respectively, to these three groups. The results of this classification are shown in Table 3 and these will form the basis for the assessment of losses in the subsequent stage of the project.

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Table 3. The Level of Expected Damage for the Different Districts of the Odunpazari Municipality (0 = "Light"; 1 = "Light-moderate"; 2 = "Moderate").

District	Mean damage ratio (MDR)	Damage state	District	Mean damage ratio (MDR)	Damage state
Akarbası	27.56	1	Huzur	23.65	0
Akcaglan	26.95	1	İstiklal	27.61	1
Akcami	25.20	1	Karapinar	23.06	0
Alanonu	24.66	0	Kirmizitoprak	27.95	1
Arifiye	28.12	2	Kurtulus	26.68	1
Buyukdere	24.13	0	Orhangazi	24.19	0
Cankaya	24.79	0	Orta	24.49	0
Cunudiye	23.60	0	Osmangazi	25.08	1
Dede	23.88	0	Pasa	24.41	0
Deliklitas	28.47	2	Sarkiye	23.70	0
Emek	24.56	0	Sumer	36.48	2
Erenkoy	23.44	0	Visnelik	28.96	2
Gokmeydan	26.89	1	Yenidogan	23.31	0
Goztepe	24.33	0	Yenikent	29.51	2
Gultepe	24.35	0	Yildiztepe	24.02	0
Gundogdu	23.62	0			

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