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SEISMIC RISK ANALYSIS
for the CITY of ANKARA

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ABSTRACT

Turkey is located in the Alp-Himalaya earthquake belt that extends from Azor islands to Southeast Asia. North Anatolian Fault Zone, Aegean Graben System, East Anatolian Fault and Southeast Anatolian Thrust are the most important faults of Turkey and also they are quite active. North Anatolian Fault Zone extends the East-West direction at the Northern part of Turkey and accepted as a dextral strike slip fault the relative motion between the Anatolian block and Eurasian plate. It has been separated four seismogenic sources based on seismological and geological criteria by Gülkan et all, 1993. The region between Dokurcun and Kargı consists of Dokurcun-Gerede, Akyazı-Bolu, Bolu-Eskipazar, Ismetpaşa-Kargı, Çerkeş-Ilgaz and Kurşunlu-Kargı fault segments has been selected seismogenic source for this study because of the most near source to Ankara.

The Ministry of Public Works and Settlement published Seismic Hazard Map of Turkey in 1996. It based on expected a maximum acceleration value that has calculated with probabilistic method. It assumes that a normal construction, which has 50 years of economical life, may not be exposed larger than these expected maximum acceleration values with 90 percent probability. The whole country is divided into the 5 different hazard zones. Ankara City is located in the fourth degree earthquake zone in accordance with this map. It means that 0.1-0.2 g maximum acceleration is expected at this city. 8 percent of the surface area of Ankara province is in the first degree hazard zone, 21 percent in the second degree hazard zone, 32 percent in the third degree hazard zone and 38 percent in the fourth degree hazard zone (Özmen et all, 1997).

We assumed that the source of destructive earthquake may effect the Ankara City is only linear. This line has been explained above. This region having latitudes 40.90N-40.40N and 41.30N-41.00N and longitudes 30.60E-35.20E has been having dimensions 56 km x 387 km. Seven big and destructive earthquakes have been recorded at this region between 1881-1997 years. One of them The Bolu-Gerede earthquake occurred in this seismogenic source that has magnitude Ms = 7.4 on the Richter Scale, maximum intensity (MSK) Io = X, epicenter 40.80N latitude 32.20E longitude and on February 1,1944 caused some damage in Ankara city especially around Yenişehir and Ankara castle. It seems that Ankara will be affected much more from a future earthquake with similar magnitude.

The aim of this study is to determine the probabilities for the generation of some earthquakes in this seismogenic source in the future years using Annual Extreme Values Method of Gumbel (1958) by using the earthquakes equal or greater than $M \geq 4$ that occurred for the time interval 1881-1997. Also, By deterministic approach, maximum ground acceleration for the city of Ankara is to

calculate from expected maximum magnitude in the seismogenic source using different attenuation relations.

Richter and Gutenberg (1942) described a methodology for estimating the magnitudes of future earthquakes, by a statistical scheme in which all earthquakes of the past, of almost any size and any number may be included in the computations. If however, the seismic history data is available only for the largest earthquakes of the past, then Annual Extreme Values Method of Gumbel may prove to be very useful and effective. Because, the lack of historical data and the deficiencies of the relevant earthquake magnitude for any particular year (Tezcan, 1996).

According to this method proposed by Gumbel, the distribution of the annual maximum earthquake magnitudes is given by:

$$G(M) = e^{-\alpha e^{-\beta M}}$$

M: Magnitude of earthquake

α,β: Regression coefficient

G(M): Probability of not exceeding the earthquakes having magnitudes more than M in one year

INTRODUCTION

Turkey is located in the Alp-Himalaya earthquake belt that extends from Azor islands to Southeast Asia. The North Anatolian Fault Zone (NAFZ), Aegean Graben System (AGS), East Anatolian Fault (EAF) and Southeast Anatolian Thrust (SAT) are the most important in Turkey and also they are quite active faults. The North Anatolian Fault Zone extends East-West direction at the Northern part of Turkey and accepted as a dextral strike slip fault the relative motions between the Anatolian block and Eurasian plate. Figure 1 shows both distribution of the earthquake epicenters equal or greater than magnitude $M \geq 4$ for a period 1881-1998 and active fault lines (Saroglu et al., 1992). Epicenters are concentrated on the NAFZ, EAF, AGS and SAT.

NAFZ has been separated four seismogenic sources based on seismological and geological criteria by Gülkan et al (1993). The region between Dokurcun and Kargı consists of Dokurcun-Gerede, Akyazı-Bolu, Bolu-Eskipazar, Ismetpaşa-Kargı, Çerkeş-Ilgaz and Kurşunlu-Kargı fault segments has been selected seismogenic source for this study because of the most near source to Ankara.

The aim of this study is to determine the probabilities for the generation of some earthquakes in this seismic source in the future. Annual Extreme Values Method of Gumbel (1958) has applied and the earthquakes equal or greater than $M \geq 4$ that occurred for the time interval 1881-1998 have been used. Also, by deterministic approach, the maximum ground acceleration and intensity and Damage State for the city of Ankara calculated from expected maximum magnitude in the seismic source using different attenuation relations.

The Ministry of Public Works and Settlement published Seismic Hazard Map of Turkey in 1996. It based on expected a maximum acceleration value that has calculated with probabilistic method. It assumes that a normal construction, which has 50 years of economical life, may not be exposed larger than these expected maximum acceleration values with 90 percent probability. The whole country is divided into the 5 different hazard zones. Ankara City is located in the fourth degree earthquake zone in this map. It means that 0.1-0.2 g maximum acceleration is expected at this city. 8 percent of the surface area of Ankara province is in the first degree hazard zone, 21 percent in the second degree hazard zone, 32 percent in the third degree hazard zone and 38 percent in the fourth degree hazard zone (Özmen et al 1997) (Figure 2).

APPLICATION OF GUMBEL`S ANNUAL EXTREME VALUES METHOD FOR ANKARA CITY

Gutenberg - Richter described a methodology for estimating the magnitudes of future earthquakes using the past earthquakes. However, It is very hard to find complete them. That's why Gumbel`s Annual Extreme Values Method is interested with only largest past earthquakes may be very useful and effective.

According to the extreme values method proposed by Gumbel, the distribution of the annual maximum earthquake magnitudes is given by :

$$G(M) = e^{-\alpha e^{-\beta M}} \quad (1)$$

M: Magnitude of earthquake

α,β: Regression coefficient

G(M): Probability of not exceeding the earthquakes having magnitudes more than M in one year

Gutenberg-Richter (1956) have proposed the following relationship which relates the earthquake magnitude to the total number of earthquakes in one year:

$$\mathrm{LogN} = a - bM \quad (2)$$

a, b : Regressions coefficients

N : The number of earthquakes in one year whose magnitude is M or greater

There are as following the correlation's between Gumbel and Richter formulations (Tezcan, 1996).

$$\alpha = 10^{a}, \quad a = \mathrm{Log}\alpha \quad (3)$$

$$\beta = b / \mathrm{Loge}, \quad b = \beta\mathrm{Loge} \quad (4)$$

$$N = \alpha e^{-\beta M} = -\mathrm{LnG} \quad (5)$$

In order to find Gumbel`s regressions coefficients, Firstly maximum earthquakes for every year have been selected from earthquake catalogues (Gencoglu, 1986 and Yatman et al 1993) as in Table 1. We assumed Mmax = 4 for years with no earthquakes. And the number of this earthquake (j) and relative frequency (f = j / (n+1)) have been determined (n: seismic history period being investigated). Then G(M), N and LogN values calculated using (1) and (5) equals as in Table 2.

Table 1 : Annual maximum earthquake magnitudes for time interval 1881 – 1998 (We assumed Mmax = 4 for years with no earthquakes)

Year	**Mmax**	Year	**Mmax**	**Year**	**Mmax**
1902	4.9	1943	7.2	1957	7.1
1910	6.2	1944	7.4	1958	4.4
1918	5.8	1945	4.9	1959	4.2
1923	5.2	1946	5.0	1964	4.6
1927	5.0	1947	4.9	1966	5.2
1929	4.8	1948	4.3	1967	6.8
1935	5.2	1949	5.1	1968	4.5
1936	4.8	1951	6.9	1971	4.2
1938	5.1	1952	4.3	1977	5.8
1940	4.9	1953	6.0	1979	4.7
1942	5.4	1955	4.6		

Table 2 : Calculations for Gumbel Annual Maximum Distributions

M	**j**	**f**	**G(M)**	**N=-lnG**	**LogN**
4	85	0.72	0.72	0.3280	-0.48408
4.2	2	0.02	0.74	0.3048	-0.51602
4.3	2	0.02	0.75	0.2820	-0.54968
4.4	1	0.01	0.76	0.2709	-0.56723
4.5	1	0.01	0.77	0.2598	-0.58532
4.6	2	0.02	0.79	0.2381	-0.62327
4.7	1	0.01	0.80	0.2274	-0.64323
4.8	2	0.02	0.81	0.2063	-0.68542
4.9	4	0.03	0.85	0.1655	-0.78116
5	2	0.02	0.86	0.1457	-0.83651
5.1	2	0.02	0.88	0.1263	-0.89862
5.2	3	0.03	0.91	0.0979	-1.00941
5.4	1	0.01	0.92	0.0886	-1.05279
5.8	2	0.02	0.93	0.0702	-1.15364
6	1	0.01	0.94	0.0612	-1.21357
6.2	1	0.01	0.95	0.0522	-1.28245
6.8	1	0.01	0.96	0.0433	-1.36354
6.9	1	0.01	0.97	0.0345	-1.46235
7.1	1	0.01	0.97	0.0258	-1.58918
7.2	1	0.01	0.98	0.0171	-1.76715
7.4	1	0.01	0.99	0.0085	-2.07004

Using the least squares method the regression coefficients, " a " and " b " have been calculated for this seismic source (Figure 3).

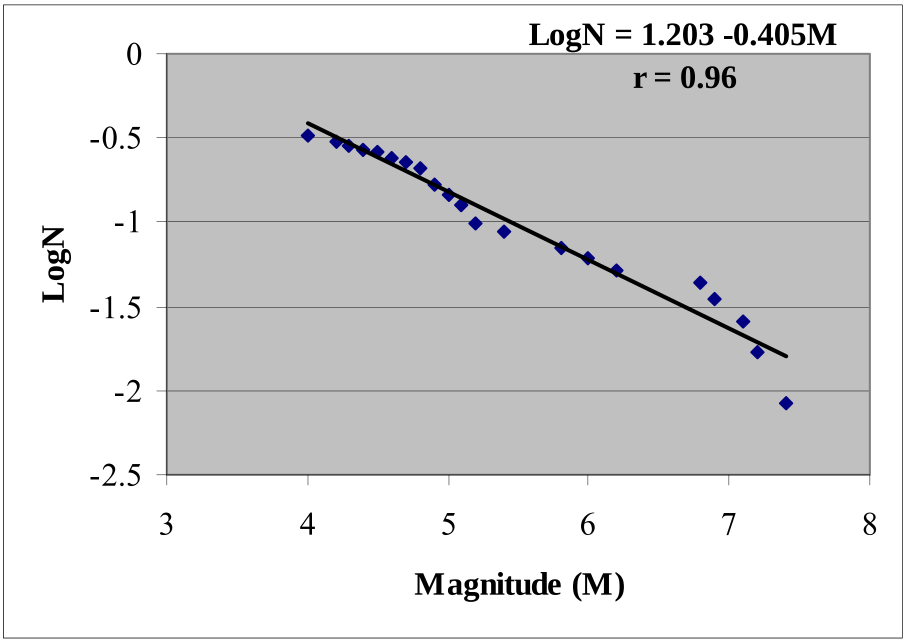

Figure 3 : Magnitude – Frequency Relation

Magnitude – frequency relation have been found for this area as following:

LogN = 1.203 – 0.405M

Gumbel`s regressions coefficients (α, β) have been calculated using the magnitude-frequency relation as follows:

$$\alpha = 10^{a} = 10^{1.203} = 15.96$$

$$\beta = b / \log e = 0.93$$

The earthquake number greater than a certain magnitude M for one year (N(M)), return period (Tr), risk for one year (R_1) and for D year have been calculated using the following formulas (Tezcan, 1996):

$$N(M) = \alpha \exp^{-\beta M}$$

$$Tr = 1 / N(M)$$

$$R_1 (M) = 1 - e^{-N(M)}$$

$$R_D (M) = 1 - e^{-DN(M)}$$

The probabilities of earthquake occurrence for the seismic source are calculated for periods of T = 1, 50, 100 years and magnitudes of M = 5.0, 5.5, 6.0, 6.5, 7.0, 7.5 and They are presented in Table 3.

Table 3 : The probabilities of earthquake occurrence for this seismic source

M	n(M)	R_1	50N	R_{50}	100N	R_{100}	Return Period
5	0.15	0.14	7.53	1.00	15.07	1.00	6.64
5.5	0.09	0.09	4.73	0.99	9.45	1.00	10.58
6	0.06	0.06	2.96	0.95	5.93	1.00	16.86
6.5	0.04	0.04	1.86	0.84	3.72	0.98	26.88
7	0.02	0.02	1.17	0.69	2.33	0.90	42.85
7.5	0.01	0.01	0.73	0.52	1.46	0.77	68.31

The probability of an earthquake occurrence of equal or greater than magnitude = 7.5 in 100 years within this area was calculated 77 percent and its return period is 68 years.

For given annual risk (R_1), We can calculate the maximum magnitude and the risk (Rd) for given structure life (Td) using the following formulas (Tezcan, 1996):

$$\mathbf{M = Ln [-\alpha / Ln (1-R_1)] / \beta}$$

$$Rd = 1 - (1-R_1)^{Td}$$

We accepted the annual risk $R_1 = 0.10$ and $R_1 = 0.15$ for residential buildings, $R_1 = 0.05$ for important public buildings and $R_1 = 0.005$ for nuclear power plants and calculated maximum magnitude and the risk of given structure life for this annual risks (Table 4).

Table 4 : Annual risk, Magnitude and Risk of given structure life

R_1	M	R(1)	R(30)	R(50)	R(75)	R(100)
0.005	8.6	0.005	0.14	0.22	0.31	0.39
0.05	6.2	0.05	0.79	0.92	0.98	0.99
0.1	5.4	0.1	0.96	0.99	1.00	1.00
0.15	4.9	0.15	0.99	1.00	1.00	1.00

The probability of an earthquake occurrence of annual risk $R_1 = 0.05$ in 50 years structure life has been calculated 92 percent and Magnitude value for this annual risk has been found 6.2.

SEISMIC RISK OF ANKARA METROPOLITAN CITY

We assumed that the source of destructive earthquake may effect the Ankara City is only linear. This line has been explained above. This region having latitudes 40.90N-40.40N and 41.30N-41.00N and longitudes 30.60E-35.20E has been having dimensions 56 km x 387 km (Figure 4). Seven big and destructive earthquakes have been recorded at this region between 1881-1998 years. The Bolu-Gerede earthquake that has magnitude Ms = 7.4 on the Richter Scale, maximum intensity (MSK) Io = X, epicenter 40.80N latitude 32.20E longitude and on February 1,1944 caused some damage in Ankara city especially around Yenişehir and Ankara castle is one of earthquakes occurred in this seismic source. It seems that Ankara will be affected much more from a future earthquake with similar magnitude.

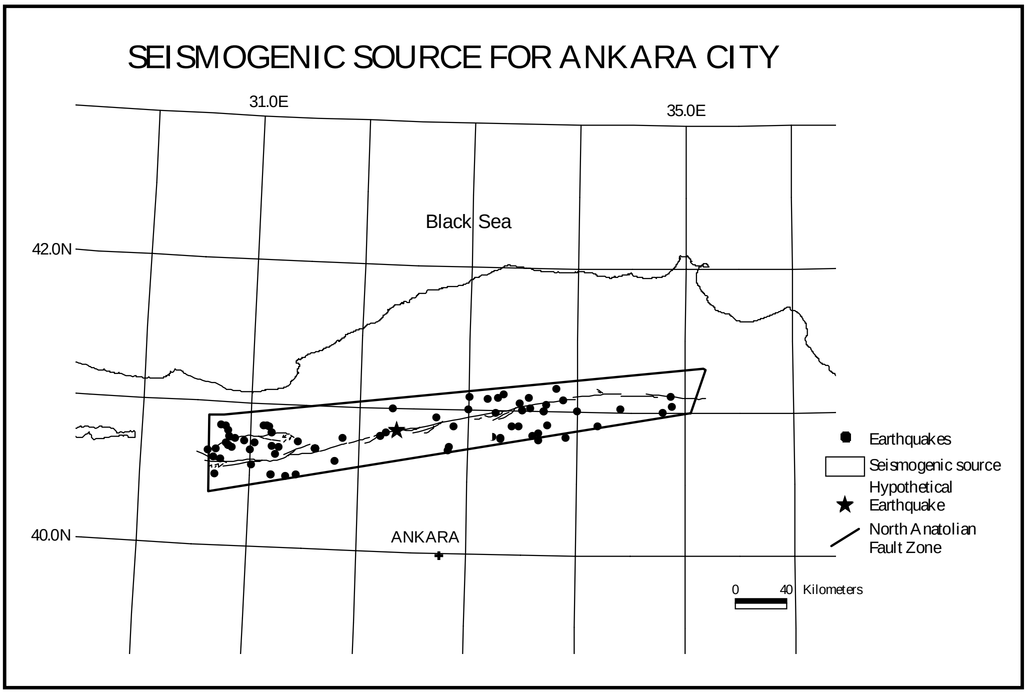

Figure 4 : Seismic source for Ankara city

By deterministic approach, maximum ground acceleration and MSK intensity for the city of Ankara have been calculated from expected maximum magnitude in the seismic source using different attenuation relations. Maximum ground accelerations are computed using the attenuation relations of Campbell, 1981, Fukishima et al (1988) Aydan et al (1996) and Inan, E. (1998). MSK Intensity is computed using the attenuation relation of Erdik et al (1983) (Table 5). The shortest distance of Ankara to NAFZ is 100 km and the average focal depth in the seismic source is 27 km.

Table 5 : Peak ground acceleration and intensity for Ankara city

For Ankara City Center			Peak Ground Acceleration(cm/sn^2)				Intensity
	R	**M**	**Inan**	**Aydan**	**Campbell**	**Fukishima**	**Erdik**
Residential Building	0.15	4.9	7	16	3	9	2.2
	0.1	5.4	14	27	6	15	3.0
Important Building	0.05	6.2	38	58	15	32	4.2
Nuclear Power Plant	0.005	8.6	843	525	239	304	7.9
Hypothetical Earthquake	0.01	7.5	204	194	71	108	6.2

Attenuation relations using this study as follows:

- $PHA = 0.0185 \exp(1.28M)(R + c(M))^{-1.75}$ (Campbell, 1981)

PHA : Average of horizontal acceleration (g)

M: Magnitude ($M < 6 \Rightarrow M = M_L$; otherwise $M = Ms$)

R: Shortest distance to fault (km)

- $Log(PHA) = 0.41M – 0.0034R – Log(R + 0.032*10^{0.41M}) + 1.30$ (Fukushima et al., 1988)

PHA : Average of horizontal acceleration (gal)

M : Surface Magnitude, R: Shortest distance to fault (km)

- $a_{max} = 2.8 (e^{0.9Ms} e^{-0.025R} – 1)$ (Aydan et al (1996)

a_{max} : Maximum acceleration (gal)

Ms: Surface Magnitude, R: Shortest distance to fault (km)

- $LogPA = 0.56M – 0.827LogR – 0.236$ (Inan, E., 1998)

PA: Maximum Horizontal Acceleration (gal),

M: Surface Magnitude, R: Shortest distance to fault (km)

- $I = 0.34 + 1.54M – 1.24 LnR$ (Erdik et al., 1983)

I : MSK Intensity

M : Surface Magnitude R : Shortest distance to fault (km)

If an earthquake of magnitude = 7.5, probability of occurrence in 100 years was calculated 77 percent, occurred at this seismic source. How Ankara City will be affected from this earthquake?

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In this study, we used vulnerability rates that are developed by Ergunay et al 1990 (Table 6) and Erdik et al 1996 (Table 7).

Table 6 : Vulnerability rates for R/C Frame Structures

	INTENSITY (MSK)				
Damage States	V(%)	VI(%)	VII(%)	VIII(%)	IX(%)
No damage	**95**	**80**	**60**	**15**	**10**
Slight damage	**5**	**18**	**20**	**30**	**25**
Medium damage	**0**	**2**	**14**	**40**	**35**
Heavy damage	**0**	**0**	**6**	**15**	**30**

Table 7 : Vulnerability rates for R/C Frame Structures that is in the middle height and multi-storey

	INTENSITY (MSK)			
Damage States	VI(%)	VII(%)	VIII(%)	IX(%)
No and Slight damage	**91**	**78**	**50**	**28**
Slight and medium damage	**7**	**17**	**37**	**50**
Heavy damage and collapse	**2**	**5**	**13**	**22**

In according to census of 1995 building There are 993 419 building in Ankara city. We assumed R/C frame construction of all building in this city at this study. Because building stock is unclassified in the census. We calculated MSK intensity I = VI using by Erdik`s intensity attenuation relations for Ankara city. Damage State for Ankara City has been predicted using vulnerability rates in Table 6 and Table 7 and They have been showed in Table 8.

Table 8 : Expected damage for Ankara city

Vulnerability rates of Ergunay		Vulnerability rates of Erdik	
Damage States	Expected Damage	Damage States	Expected Damage
No damage	**794 735**	No and slight damage	**904 011**
Slight damage	**178 815**	Slight and medium damage	**168 881**
Medium damage	**19 868**	Heavy damage and collapse	**19 868**
Heavy damage and collapse	**0**		

Ergunay et al (1990) have developed an empirical relation between heavy damage and casualty as follows:

$D = 0.003\ H^{1.32}$ (For reinforced concrete buildings)

D: Total number of deaths

H: Total number of collapsed and heavily damaged building

The calculated number of death is zero considering vulnerability rates of Ergunay, while the number of death is 1415 persons considering vulnerability rates of Erdik.

CONCLUSIONS

The maximum ground accelerations and intensity have been proposed as a = 27 cm/sec^2 for normal building, a = 58 cm/sec^2 for important building and a = 525 cm/sec^2 for nuclear power plants on the main rock and intensity I = 6.2 for Ankara city.

Bolu-Gerede (1944), magnitude M = 7.4, earthquake that occurred on the North Anatolian Fault Zone caused some damage in Ankara city. The city population of Ankara at 1945 was 279 491. Today is population approximately 10 times more censuses. It is possible that Ankara will be affected much more from an earthquake with similar or a little big magnitude may be occurring in the future.

For a hypothetical earthquake of magnitude M = 7.5 on the North Anatolian Fault Zone It is no expected any heavy damage and collapse building and deaths for this city. But 2 percent of buildings at Ankara City will be medium damage and 18 percent will be slight damage.

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