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THE SEISMIC CHARACTERISTICS OF TURKISH EARTHQUAKES

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ABSTRACT

Turkey is a well-known earthquake-prone country and its earthquakes are generally of in-land type. The authors developed a data-base for *Turkish Earthquakes* for the last 2000 years and attempted to find out interrelations among seismic characteristics of these earthquakes. The data-base is named *TURDEP* and it is coded using a soft wear *DBASE* on a personal computer. Data files to study the interrelations among seismic characteristics are created using a program coded in *BASIC* from the data-base data. A soft-wear code called *NGRAPH* is used for graphical presentations of data. This integrated data-base system is described and seismic characteristics of Turkish earthquakes and their interrelations are presented and discussed.

KEYWORDS

Turkey; earthquakes; seismicity; characteristics; faults; data-base

INTRODUCTION

Turkey is a well-known earthquake-prone country and its seismic past is well documented (Ergin et al. 1967, Ayhan et al. 1981, Eyidoğan et al. 1990, Gençoğlu et al. 1990, Bayülke et al. 1990). Most of earthquakes are concentrated along the North Anatolian Fault (NAF), East Anatolian Fault (EAF), North East Anatolian Fault (NEAF) and West Anatolian Fault System (WAFS) as a result of north-ward motion of Arabian plate and African Continent and these earthquakes are generally of in-land type which are more destructive than off-shore earthquakes even their magnitude could be smaller (Şengör 1980, Barka and Gülen 1987, Barka and Kadinsky-Cade 1988, Toksöz et al. 1979, Aydan and Paşamehmetoğlu 1994) (Figure 1).

The authors developed an integrated data-base system for *Turkish Earthquakes* for the last 2000 years with the purpose of finding out interrelations among their seismic characteristics. The data-base is named *TURDEP* and it is developed on a personal computer. In this article, this integrated data-base system is described and seismic characteristics of Turkish Earthquakes and interrelations among them are presented and discussed in order to provide information for seismic design of engineering structures as well as for forecasting earthquakes.

INTEGRATED DATA-BASE SYSTEM

Data-base System

The data base was named *TURDEP*, which stands for the first three letters of Turkish Earthquakes in Turkish, and was developed on a personal computer using a soft-wear *DBASE*. The items of the data-base system were chosen as follows:

Group 1: Name, location (Latitude (Lat), Longitude (Lon)), Depth (Hd)
Group 2: Magnitude (M_b, M_s, Mercalli Intensity I_o)
Group 3: Peak ground acceleration (Acmax), dominant period(Tper), ratio of maximum vertical acceleration to maximum horizontal acceleration (Av/Ha)
Group 4: Time (year (Year), month (Mo), day (Da), hour (Ho), minute (Mi))
Group 5: Characteristics of rupture plane (dip direction (Ddr), dip (Dip), slip direction (Sdr), surface rupture length (Len), maximum relative displacement (Dis))
Group 6: Type of rupturing (Strike-slip (Slst), Normal faulting (Norf), Reverse faulting (Revf))
Group 7: Earthquake grouping (North Anatolian Fault (NAF), North East Anatolian Fault (NEAF), Central Anatolian Fault System (CAFS), East Anatolian Fault and Bitlis-Zagros Thrust Zone (EAFBZ), West Anatolian Fault System (WAFS))

Table 1 shows an example list of entries of the data-base system.

Table 1. A list of entries of data-base system

Record	Name of Earthquake	Location			Magnitude					Time						Rupture plane					Rupture Type		Group
No		Lat	Lon	Hd	Mb	Ms	Io	Acmax	Tper	Year	Mo	Da	Ho	Mi	Av/Ah	Ddr	Dip	Sdr	Len	Dis	Type1	Type2	
101	KAS-PETHIYE	36.11	29.20	22.0	5.6	6.3	7	0.0	0.00	1969	1	24	23	12	0.00	100	74	98	0	0	Revf		WAFS
102	GONEN	40.10	27.50	4.0	5.6	5.7	7	0.0	0.00	1969	3	3	0	59	0.00	219	65	45	0	0	Revf	Slst	WAFS
103	DEMIRCI-GORDES	39.10	28.45	12.0	5.6	6.5	7	0.0	0.00	1969	3	25	13	22	0.00	90	40	104	0	0	Norf		WAFS
104	ALASEHIR	38.55	28.46	4.0	5.9	6.5	8	0.0	0.00	1969	3	28	1	48	0.00	281	34	-90	36	13	Norf		WAFS
105	KARABURUN	38.47	26.41	16.0	5.6	5.8	6	0.0	0.00	1969	4	6	2	49	0.00	116	60	-90	0	0	Norf		WAFS
106	GEDIZ	39.21	29.51	18.0	6.0	7.1	9	0.0	0.00	1970	3	28	21	2	0.00	281	34	-90	40	225	Norf		WAFS
107	KUTAHYA	39.10	29.80	26.0	5.5	0.0	8	0.0	0.00	1970	4	19	13	47	0.00	0	0	0	0	0			WAFS
108	DEMIRCI-GORDES	39.10	28.65	28.0	5.2	0.0	8	0.0	0.00	1970	4	23	9	1	0.00	0	0	0	0	0			WAFS
109	GURUN-SIVAS	38.87	36.81	19.0	4.7	4.8	7	0.0	0.00	1970	7	2	2	24	0.00	193	92	-33	0	0	Slst		CAFS
110	IVRINDI-BALIKESIR	39.62	27.32	10.0	5.0	5.6	9	0.0	0.00	1971	2	23	19	41	0.00	0	0	0	0	0			WAFS
111	BURDUR	37.60	29.72	30.0	6.0	6.2	8	0.0	0.00	1971	5	12	6	25	0.00	64	50	-75	40	30	Norf		WAFS
112	BINGOL	38.85	40.52	9.0	5.9	6.7	8	0.0	0.00	1971	5	22	16	43	0.00	231	81	4	38	20	Slst		EAFBZ
113	SARIKAMIS	40.42	43.88	46.0	4.9	0.0	8	0.0	0.00	1972	3	22	0	51	0.00	0	0	0	0	0			NEAF
114	VAN-EDREMIT	38.23	43.36	46.0	4.9	0.0	8	0.0	0.00	1972	7	16	2	46	0.00	0	0	0	0	0			EAFBZ
115	IZMIR	38.55	27.22	24.0	5.2	5.8	7	0.0	0.00	1974	2	1	0	1	0.00	250	65	151	0	0	Norf		WAFS
116	GELIBOLU	40.45	26.12	15.0	5.5	6.6	7	0.0	0.00	1975	3	27	5	15	0.00	279	46	-43	0	0	Norf		NAF
117	LICE	38.51	40.77	32.0	6.0	6.6	8	0.0	0.00	1975	9	6	9	20	0.00	250	54	43	26	60	Revf	Slst	EAFBZ
118	ARDAHAN	41.01	42.97	25.0	4.8	5.1	8	0.0	0.00	1976	3	25	11	55	0.00	0	0	0	0	0			NEAF
119	IGDIR	39.85	43.64	14.0	4.6	5.1	7	0.0	0.00	1976	4	2	16	58	0.00	0	0	0	0	0			NEAF
120	ARDAHAN	40.96	42.87	30.0	5.0	5.5	8	0.0	0.00	1976	4	29	22	18	0.00	0	0	0	0	0			NEAF
121	DENIZLI	37.71	29.00	20.0	5.0	4.9	6	340.0	0.50	1976	8	19	1	12	0.60	0	0	0	0	0	Norf		WAFS
122	CALDIRAN	39.05	44.00	10.0	6.9	7.3	9	335.0	0.00	1976	11	24	12	22	0.71	196	86	168	54	370	Slst		EAFBZ
123	PALU-ELAZIG	38.58	40.03	29.0	5.0	4.8	7	0.0	0.00	1977	3	25	2	39	0.00	232	86	-8	0	0			EAFBZ
124	IZMIR	38.41	27.19	24.0	5.3	5.6	7	221.0	0.50	1977	12	16	7	37	0.19	0	0	0	0	0	Norf		WAFS
125	UZUMLU-ERZINCAN	39.67	39.88	48.0	4.7	4.5	7	0.0	0.00	1978	2	15	3	17	0.00	0	0	0	0	0			NAF
126	BURDUR	37.53	30.02	28.0	4.6	4.5	7	126.0	0.00	1978	7	29	64	34	0.00	0	0	0	0	0			WAFS
127	KARABURUN	38.79	26.57	15.0	5.9	5.8	6	157.0	0.00	1979	6	14	11	44	0.00	0	0	0	0	0			WAFS
128	PULUMUR-TUNCELI	40.65	42.75	3.0	4.3	0.0	7	0.0	0.00	1980	4	25	0	57	0.00	0	0	0	0	0			NAF
129	TERCAN-ERZURUM	39.90	40.31	37.0	5.1	4.4	7	0.0	0.00	1980	11	18	3	14	0.00	0	0	0	0	0			NEAF
130	BULANIK-MUS	39.23	41.90	38.0	5.4	5.2	7	0.0	0.00	1982	3	27	19	57	0.00	0	0	0	0	0			NAF
131	HORASAN	40.07	42.26	62.0	4.7	3.8	7	0.0	0.00	1982	5	19	13	32	0.00	0	0	0	0	0			NEAF
132	CAYIRLI-TERCAN	39.89	40.43	45.0	5.0	4.1	7	0.0	0.00	1983	4	6	7	35	0.00	0	0	0	0	0			NEAF
133	KULU-BALA	39.30	33.06	36.0	4.7	4.4	7	0.0	0.00	1983	4	21	16	18	0.00	0	0	0	0	0			CAFS
134	BIGA	40.33	27.21	7.0	5.5	5.8	7	51.0	0.00	1983	7	5	12	1	0.68	46	60	94	0	0	Revf		WAFS
135	INEGOL-BURSA	40.14	29.35	12.0	5.0	4.9	7	0.0	0.00	1983	10	21	20	34	0.00	0	0	0	0	0			NAF
136	NARMAN-HORASAN	40.35	42.18	9.0	6.0	6.8	8	180.0	0.80	1983	10	30	4	12	0.42	215	64	7	8	100	Slst		NEAF
137	BALKAYA-ERZURUM	40.90	42.24	10.0	5.3	5.5	7	0.0	0.00	1984	9	18	13	26	0.00	112	79	171	0	0	Slst		NEAF
138	DOGANSEHIR-MALATYA	38.02	37.79	10.0	5.7	5.8	7	56.0	0.00	1986	6	6	3	35	0.33	52	9	60	20	0	Revf		EAFBZ
139	KUYUCAK-DENIZLI	37.94	28.56	5.0	5.4	5.7	5	0.0	0.00	1986	10	11	9	0	0.00	0	0	0	0	0			WAFS
140	MARMARA	40.93	28.07	11.0	5.0	5.1	7	0.0	0.00	1988	4	24	20	49	0.00	0	0	0	0	0			NAF
141	MURADIYE	39.12	43.91	44.0	4.9	5.1	0	49.8	0.20	1979	4	11	0	0	0.48	0	0	0	0	0	Slst		EAFBZ
142	DURSUNBEY	39.66	28.65	7.0	5.2	5.4	0	309.4	0.40	1979	7	18	10	13	0.52	0	0	0	0	0	Norf		WAFS
143	ANTAKYA	36.17	35.89	63.0	4.7	4.8	6	128.8	0.12	1981	6	30	10	59	0.97	0	0	0	0	0			EAFBZ
144	BALIKESIR	39.64	28.87	12.0	4.6	4.7	0	295.7	0.35	1984	3	29	3	6	1.23	0	0	0	0	0	Norf		WAFS
145	CAYIRLI-ERZINCAN	39.95	39.77	29.0	4.9	5.0	0	152.4	0.50	1985	8	12	2	44	0.28	0	0	0	0	0			NAF
146	KOYCEGIZ	37.00	28.70	0.0	3.5	3.6	0	144.7	0.67	1985	12	7	0	0	0.48	0	0	0	0	0			WAFS
147	ERZINCAN	39.71	39.55	29.0	6.2	6.8	9	505.0	0.50	1992	3	13	9	19	0.50	101	88	172	45	54	Norf	Slst	NAF
148	PULUMUR	39.53	39.87	16.0	5.5	6.1	7	100.8	0.50	1992	3	15	18	17	0.47	61	70	14	0	0			NAF
149	DINAR	38.10	30.02	24.0	5.7	6.0	0	294.0	0.00	1995	10	1	15	57	0.38	0	0	0	50	25	Norf	Slst	WAFS
150	DINAR	38.10	29.82	20.0	0.0	4.7	0	174.0	0.00	1995	9	26	14	58	0.32	0	0	0	0	0	Norf	Slst	WAFS

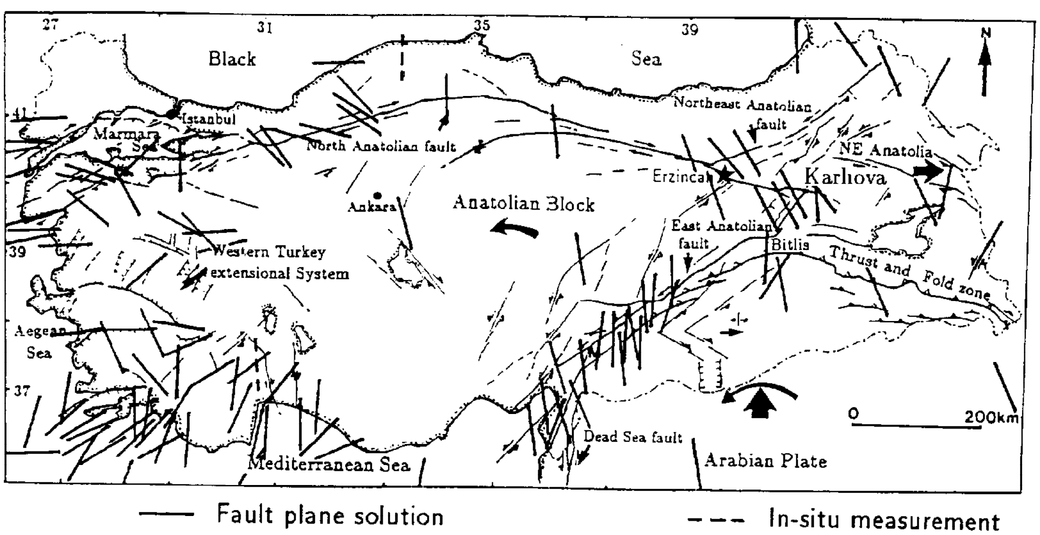

Fig. 1 Main fault systems and Tectonics of Turkey (thick linear solid and broken lines show the maximum compressive horizontal stress directions)

System for Interrelation Studies

A soft-wear program coded with *BASIC* programing language was developed to create data files for studying interrelations among seismic characteristics of earthquake data. This soft-wear is presently capable of creating data files for the following conditions:

1) Rupture type (Slst, Norf, Revf)
2) Earthquake grouping (NAF, NEAF, WAFS, CAFS, EAFBZ)
3) Magnitude range (M_{min}, M_{max})
4) Unconditional

Created data files were then plotted using a graphic softwear *NGRAPH*, examples of which are presented in the following section.

SEISMIC CHARACTERISTICS AND INTERRELATIONS

Locations of Earthquakes for the Last Century

Figure 2 shows plots of locations of earthquakes in Turkey for the last century which corresponds to the instrumented period. As seen from the figure, earthquakes concentrate along the North Anatolian Fault (NAF), North East Anatolian Fault (NEAF), Central Anatolian Fault System (CAFS), East Anatolian Fault and Bitlis-Zagros Thrust Zone (EAFBZ), West Anatolian Fault System (WAFS) as expected.

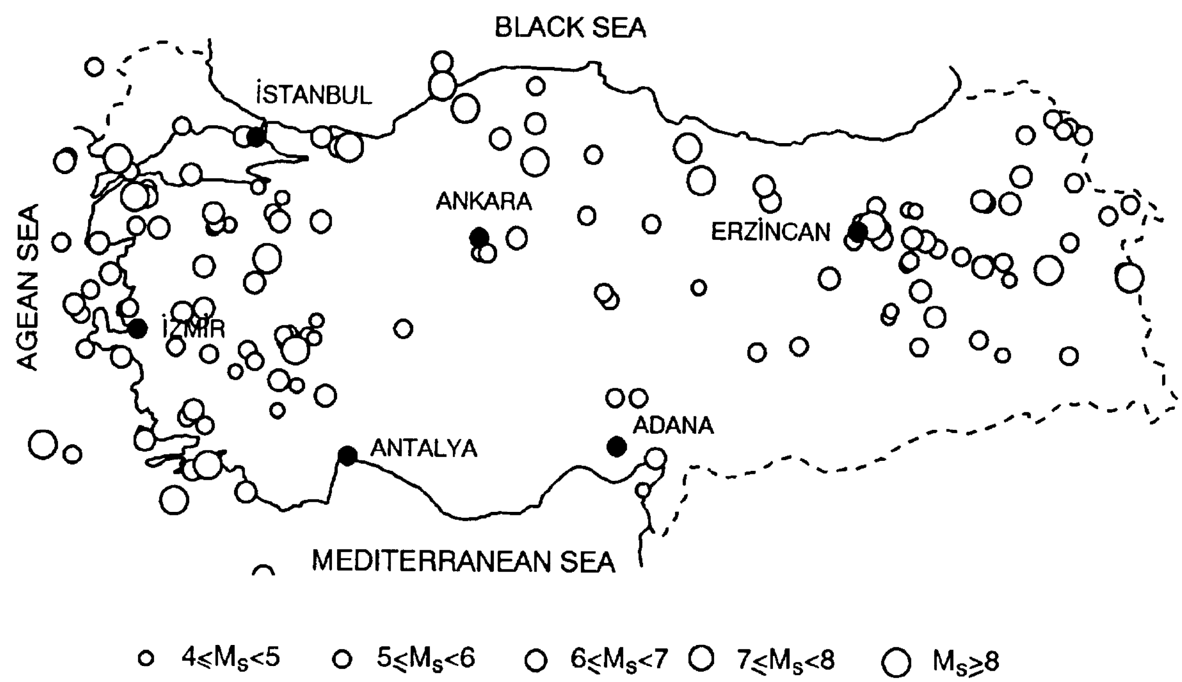

Fig. 2 Locations of earthquakes in Turkey for the last century

Relation between Magnitude M_s and Mercalli Intensity I_o

Figure 3 shows the relation between magnitude M_s and Mercalli Intensity I_o. The following linear functions were fitted to observations.

$$I_o = 1.317M_s, \quad M_s = 0.7593I_o \qquad (1)$$

It should be noted a constraint was implemented in fitting the emprical equation (1) to observations.

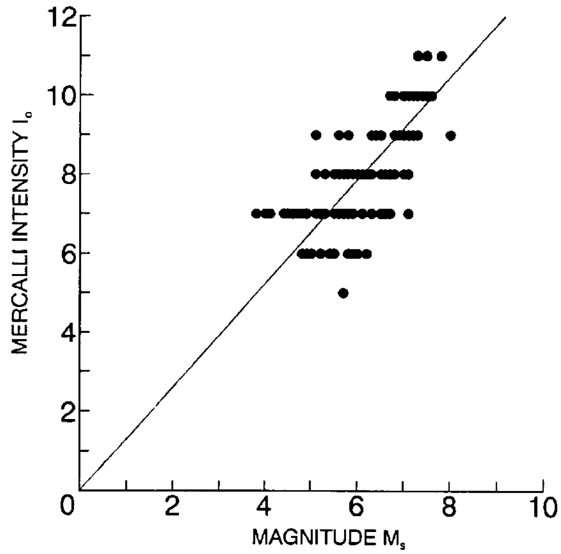

Fig. 3 Relation between magnitude M_s and Mercalli Intensity I_o

Relation between Magnitude M_s and Maximum Displacement U_{max}

Figure 4 shows the relation between magnitude M_s and maximum observed relative displacement U_{max}. As seen from the figure, the observation of movement of faults on ground surface becomes possible when the magnitude M_s is greater than 4. The following emprical function seems to be a good fit to observations.

$$U_{max} = 0.0014525M_s e^{1.31M_s} \qquad (2)$$

As expected, the magnitude of displacement of the fault increases as the magnitude of the earthquake increases.

Relation between Magnitude M_s and Surface Rupture Length L

Figure 5 shows the relation between magnitude M_s and surface rupture length L of faults. Eq. (2) exactly fits the observations except that coefficient 0.0014525 has a different physical meaning. This implies that the surface rupture length is 10^5 times maximum relative displacement U_{max} for *Turkish earthquakes* which is not very suprising if the definition of the seismic moment is considered.

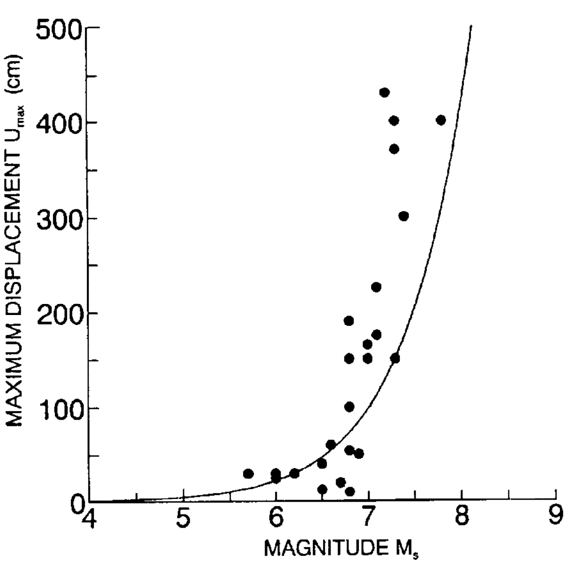

Fig. 4 Relation between magnitude M_s and maximum displacement U_{max}

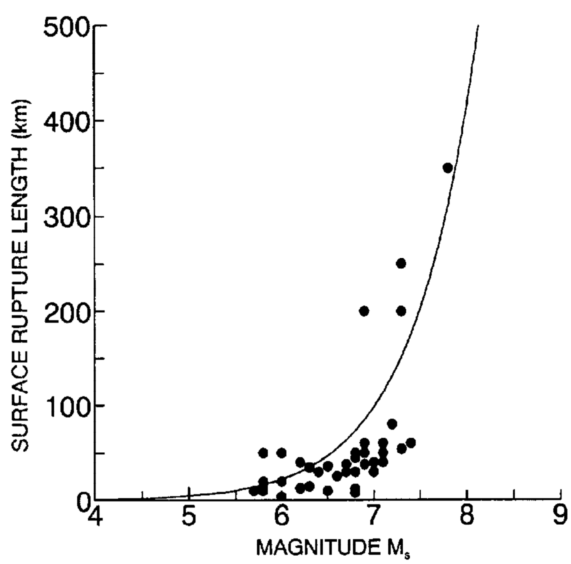

Fig. 5 Relation between magnitude M_s and surface rupture length L

Relation between Magnitude M_s and Rupture Area A

Figure 6 shows the relation between magnitude M_s and rupture area A. The following emprical function seems to be representative of observations.

$$A = 0.0032 M_s \epsilon^{1.66 M_s} \quad (3)$$

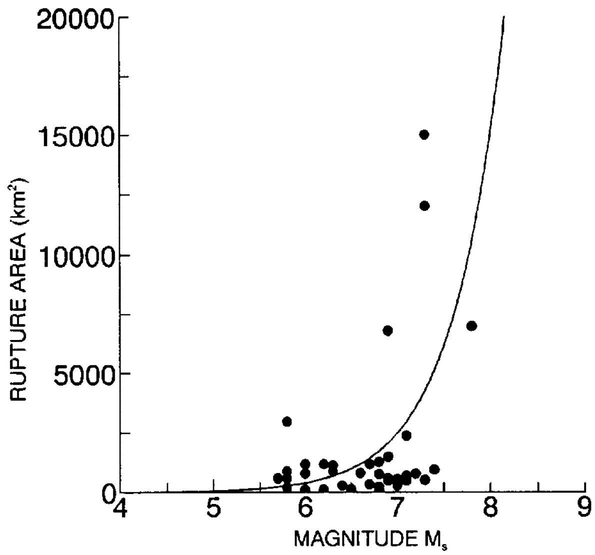

Fig. 6 Relation between magnitude M_s and rupture area A

Relation between Magnitude M_s and Peak Ground Acceleration a_{max}

Figure 7 shows the relation between magnitude M_s and peak ground acceleration. It should be noted that hypocenter distance R from strong motion stations was generally greater than 20 km. The following emprical function seems to be a good fit to observations.

$$a_{max} = 2.8(e^{0.9M_s} e^{-0.025R} - 1) \quad (4)$$

By assuming that $R = 25km$, the plot of the above function is also shown in the same figure. This function is a convolution of two exponential functions and its coefficients may be further refined as more strong motion data increases.

Relation between Magnitude M_s and Dominant Period τ_{per}

Figure 8 shows the relation between magnitude M_s and dominant period τ_{per} of observed acceleration waves. The dominant period is the one that corresponds to the spectrum of the wave with the maximum amplitude in Fourier Spectra. The following emprical function seems to be representative of observations.

$$\tau_{per} = 0.067 + 0.071 M_s \quad (5)$$

Although the number of data is not sufficient to draw any conclusion yet, the period of the dominant wave should generally be between 0.2-0.8 second in view of fracture propagation velocities reported in rock mechanics.

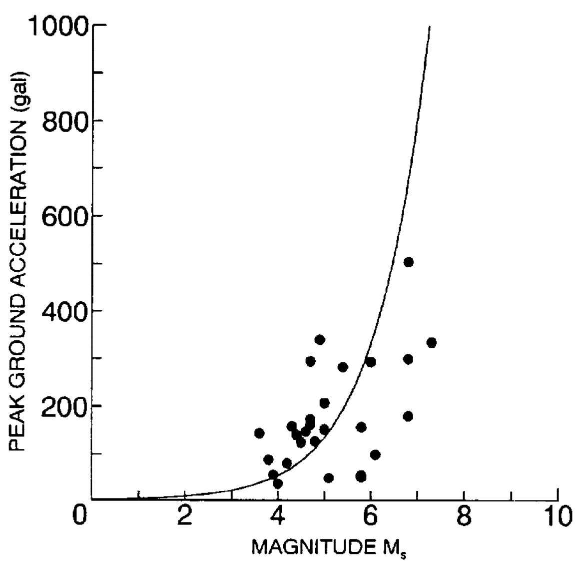

Fig. 7 Relation between magnitude M_s and maximum acceleration PGA

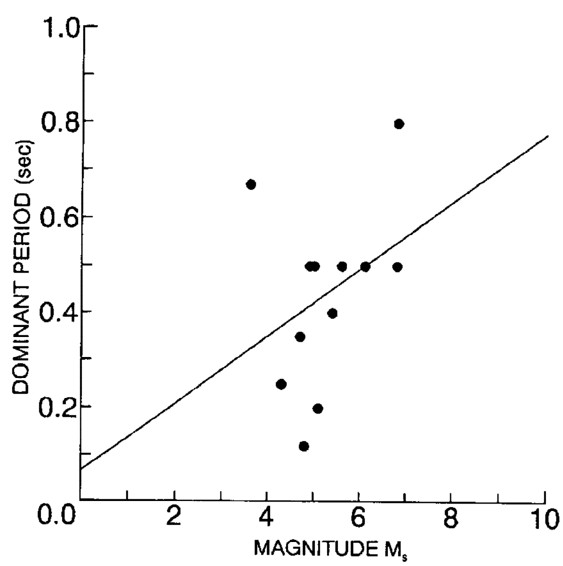

Fig. 8 Relation between magnitude M_s and dominant period of acceleration wave τ_{per}

Relation between Magnitude M_s and Ratio of Maximum Vertical Acceleration to Maximum Horizontal Acceleration $RVAHA$

Figure 9 shows the relation between magnitude M_s and the ratio of maximum vertical acceleration to maximum horizontal acceleration $RVAHA$. The following emprical function fits the observations.

$$RVAHA = 0.217 + 0.046 M_s \tag{6}$$

Since most of earthquakes are of in-land type, the ratio ranges between 0.2 to 0.8. However, the average seems to be 0.4 which implies importance of considering vertical component in the seismic design of engineering structures against in-land earthquakes.

Attenuation of Peak Ground Acceleration

Figure 10 shows the relation between hypocenter distance R and peak ground acceleration a_{max} together with a function given by Eq. (4), which is plotted for various values of magnitude M_s. It should be noted that the data plotted in Fig. 10 were obtained from another data-base system named *IVAZTURD* for the attenuation and wave characteristics of acceleration records for the strong motion wave data of Turkey. Since the number of strong motion data for *Turkish Earthquakes* is still limited, it is in-mature to draw any conclusion yet. Nevertheless, the proposed function presently seems to be a good-fit to observations.

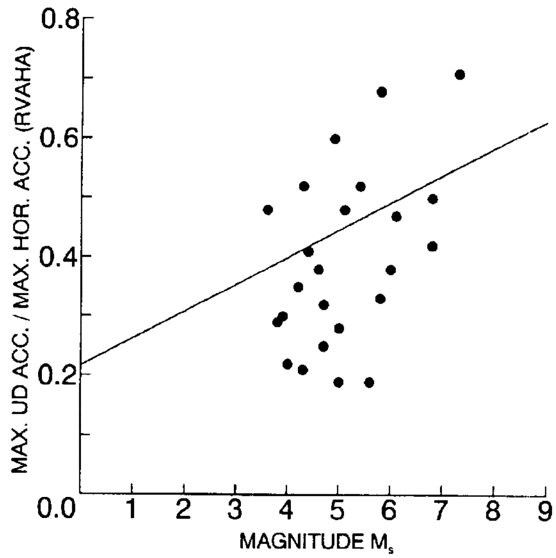

Fig. 9 Relation between magnitude M_s and maximum vertical acceleration to maximum horizontal acceleration

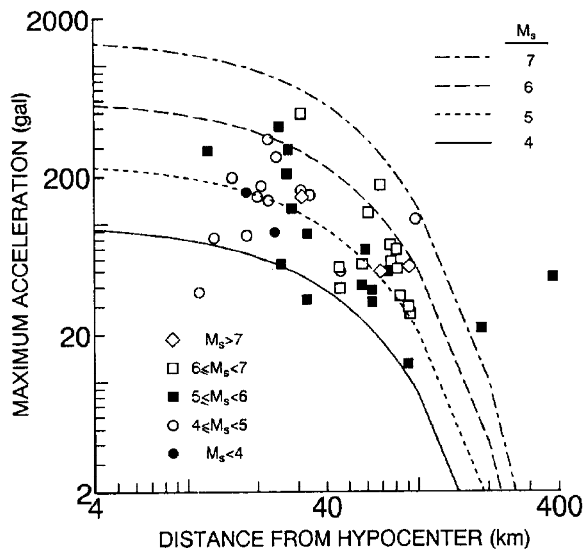

Fig. 10 Attenuation of maximum ground acceleration

EARTHQUAKE OCCURENCE PATTERN IN TURKEY

Figure 11 shows the relation between time (year) and Magnitude M_s of earthquakes for various faulting groups of Turkey. As it is noted from the figure, very large events ($M_s \geq 7$) occur at the NAF and at the EAFBZ while the magnitude of events at the WAFS and the NEAF are generally less than M_s=7. It seems that the initiation of seismic activity occurs in the near vicinity of Karlıova junction (see Fig. 1 for location) in the form of lateral strike slip and/or reverse faulting. Reverse faulting events are generally shallow ($h < 15km$) while strike-slip faulting events are more deeper. As a result, events are simultaneously or with a slight delay initiated in the WAFS in the form of normal faulting. For example, the Kuşadası earthquake (M_L = 6.0) on 06/11/1992 and the recent Dinar earthquake (M_L = 6.0) on 01/10/1995 followed the Erzincan earthquake (M_L = 6.9) on 13/03/1995 and Pülümür earthquake (M_L = 6.0) on 15/03/1995 confirm this conclusion. The events in the WAFS have smaller magnitudes as the stress state to cause normal faulting could not result in higher energy accumulation as compared with those in the NAF and the EAF. However, the frequency of events in the WAFS is greater than that of the eastern events. This is mechanically a quite natural consequence of the stress states to cause normal faulting and strike-slip faulting.

Although it is still inmature to purpose an exact model for earthquake occurence pattern in Turkey, the following model may be put forward in view of the available data:

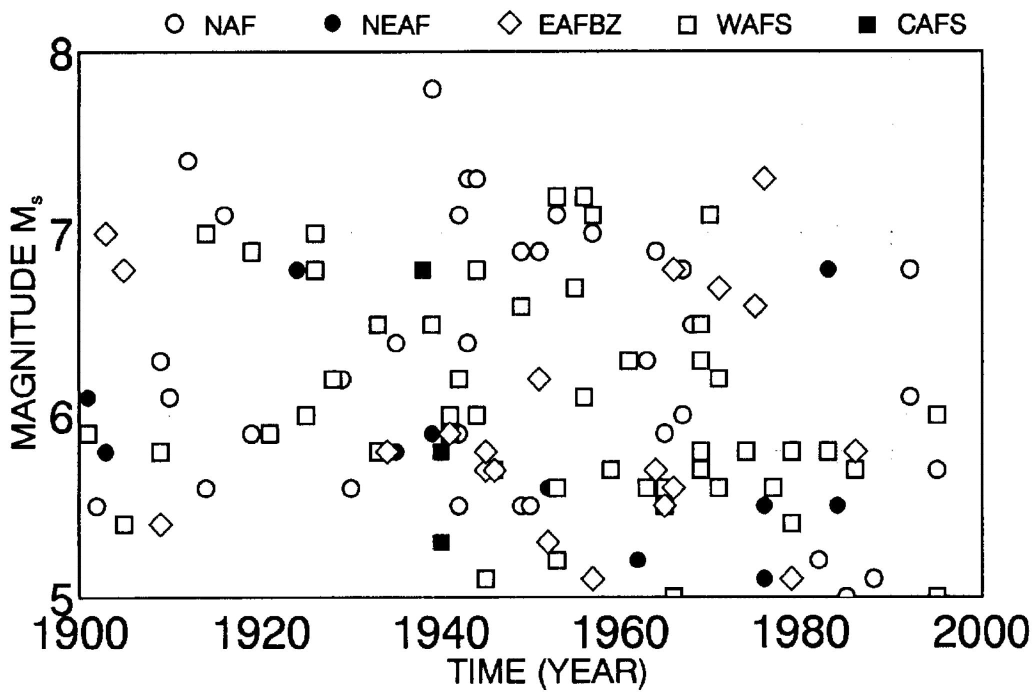

Fig. 11 Distribution of earthquakes in time

1) **Crushing and strike-slip faulting** in the vicinity of the Karlıova junction of the NAF, NEAF and EAFBZ: The driving force results from the northward moving and anti-clock wisely rotating Arabian plate. It must be noted that it is almost imposible to push the Anatolian plate westward by a purely northward-moving Arabian plate. If the anti-clock wise rotation of the Arabian plate exists, then it will provide an enough momentum to push the Anatolian plate towards the west. Recent Çaldıran earthquake (24/11/1976) validates the above statement.

2) **Uplifting and normal faulting** in the western Anatolia: The westwardly pushed Anatolian plate is restrained by the Agean plate and is uplifted by the northwardly moving African continent against the stationary Euro-Asian plate. This results in bending the western part of the Anatolian plate which causes normal faulting in the uppermost part of the crust. This results in a further growth of the host-graben structure in the western Anatolia. However, it should be noted that there is a general tendency for uplifting the whole western Anatolia. For example, the historic sea-side cities such as Efes (Ephesos) and Milet (Miletos) in the grabens of Küçük Menderes and Büyük Menderes respectively are retreated by 3 to 4 km away from the present sea shore, which validates the above conclusion.

3) **Rotation of the Anatolian Plate**: Because of the combined action of the slower rate of motion of the African plate with respect to that of the Arabian plate, westward pushing by the Arabian plate, restraining by the Agean plate and uplifting by the African plate, the Anatolian plate tends to rotate anti-clock wise, aided with the motion of the rotating Earth. This action causes subsequent events along the entire perimetry of the Anatolian plate. Without doubt the magnitude of events at bends, where stress concentrations occur, are larger than at other less restraining segments of the faults.

The information from the present data-base system and previous two dimensional elasto-plastic finite element analyses of Turkey and its close vicinity (Kasapoğlu and Toksöz 1983) confirms most of the above statements. Nevertheless, three-dimensional elasto-visco-plastic analyses with the consideration of the actual geologic structure of the Earth's crust in Turkey and its close vicinity are necessary. If these analyses are backed up by in-situ stress measurements and global and local deformation measurements, they can probably yield an exact model for the earthquake occurence pattern in Turkey.

CONCLUSIONS

An integrated data-base system *TURDEP* for *Turkish Earthquakes* was developed to study the seismic characteristics of the earthquakes of Turkey so that it may be of some help to engineers for the seismic design of structures as well as to scientists for forecasting earthquakes. This data-base system was described and the usefullness of the system was demonstrated by studying the interrelations among the seismic characteristics of the Turkish earthquakes, inspite the system still needs further improvements. It is also pointed out that such systems integrated with numerical analyses and monitoring schemes can be of great value in forecasting future earthquakes not only in Turkey but also in other countries prone to earthquakes.

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