INTERNATIONAL
EARTHQUAKE SYMPOSIUM KOCAELI 2007
22-26 OCTOBER 2007

THE STRESS DROPS IN THE NORTH ANATOLIAN FAULT (TURKEY) ZONE DURING THE 1939-1999

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Key Words: Stress drop, North Anatolian Fault Zone, Seismic Moment, Turkey

ABSTRACT *In this work, the stress – drop values are examined using macro – seismic observations of 9 major earthquakes $M_w \geq 6.5$ that occurred along the North Anatolian Fault zone during the 1939-1999 period. The stress drop associated with the earthquakes in the North Anatolian Fault zone is not strongly dependent on magnitude. The stress drop in the North Anatolian Fault zone for $M_w \geq 7.0$ is between 20 and 50 bars. For smaller earthquakes ($M_w < 7.0$) we found less than 20 bars. There are some low stress drop areas in the fault zone due to either strain accumulation or creep phenomenon.*

INTRODUCTION

The North Anatolian Fault has become widely publicized of remarkable series of earthquakes that began to occur in 1939. The fault is quite similar to some well known active strike – slip faults of the earth such as San Andreas Fault. Only the nine of major earthquakes have been investigated in detail in the field by several investigators. In this paper, we undertook some static parameters observed in the field, we tried to determine stress – drop values associated with earthquakes that occurred along the North Anatolian Fault zone during the 1939-1999 period. The List of earthquakes studied is given in **Table 1.** The distribution of epicenters of these earthquakes is given in **Figure 1.** The earthquakes of 19 August, 1966 is not included in Table 1, which may be due to different nature of faulting of this shock namely the fault plane solution for this event is not purely strike – slip faulting.

DATA BASE FOR CALCULATIONS STRESS – DROP VALUES ASSOCIATED WITH NORTH ANATOLIAN FAULT ZONE

The list of earthquakes ($6.5 \leq M_w \leq 7.9$) studied along the North Anatolian Fault zone during the 1939-1999 period, as data base is given in **Table 1.** Some of the fault parameters (as fault length, displacement) observed in the field for 9 major selected earthquakes by several investigators are given in **Table 2.** The seismic moments (M_o) values determined from different data base by several investigators are given in **Table 3.**

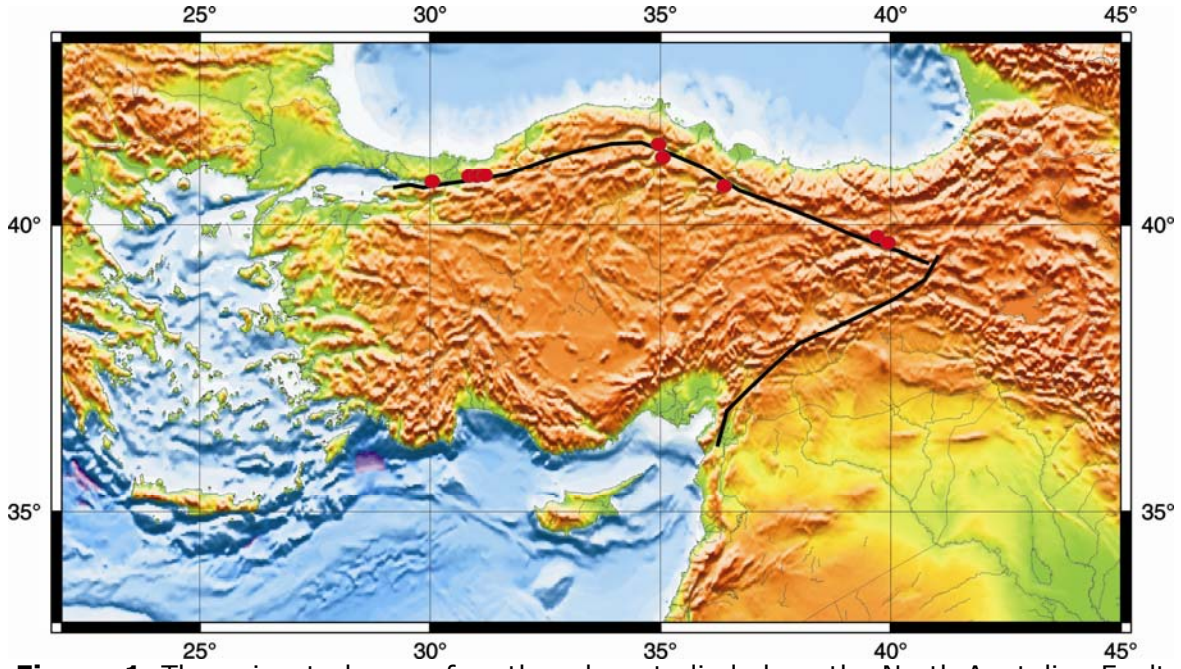

Figure-1. The epicentral map of earthquakes studied along the North Anatolian Fault Zone.

Table-1. The list of earthquakes studied along the North Anatolian Fault Zone

Date	Origin Time (GMT)	Lat (°N)	Lon (°E)	References	Moment Magnitude (M_w)	References
1939.12.26	23:57:20	39.80	39.38	[1], [2]	7.9	[3]
1942.12.20	14:03:07	40.66	36.35	[1], [2]	6.9	[3]
1943.11.26	22:20:43	40.97	33.22	[1], [2]	7.7	[3]
1944.02.01	03:22:35	41.10	33.22	[1], [2]	7.5	[3]
1957.05.26	06:33:26	40.58	31.00	[1], [2]	6.8	[3]
1967.07.22	16:56:57	40.57	30.80	[1], [2]	7.0	[3]
1992.03.13	17:18:39.9	39.71	39.60	NEIC	6.5	[3]
1999.08.17	00:01:38.5	40.702	29.997	USGS	7.4	USGS, [4], [5]
1999.11.12	16:57:20.3	40.768	31.148	USGS	7.1	USGS, [4], [5]

[1]:Karnik (1969); [2]:Dewey (1976); [3]:Stein et al.(1997); [4]:Taymaz (1999); [5]:Irmak (2000); USGS (circular 1193).

Table-2. The fault Parameters observed in the field of earthquakes studied along the North Anatolian Fault zone

Date	M_W	L(km)	U_H(cm)	References
1939.12.26	7.9	300	370	[6], [7]
		360	370	[8]
1942.12.20	6.9	50	175	[9],[10]
1943.11.26	7.7	280	150	[11],[12],[13]
			250	[8]
1944.02.01	7.5	180	350	[10],[12]
			350	[8]
1957.05.26	6.8	40	160	[13],[14]
1967.07.22	7.0	80	190	[15]
1992.03.13	6.5	30	95	[16]
		20	102	[5]
1999.08.17	7.4	140	500	[4]
		-	482	[5]
		120	450	[17]
		136.1	470-490	[18]
		110	450-501	[19]
		150	---	[25]
1999.11.12	7.1	45-50	420	[4]
		40	256	[5]
		45.2	580±70	[18]

L : Fault Lenght; U_H : Maximum Horizontal Displacement, M_w= Moment Magnitude

[4]:Taymaz 1999; [5]:Irmak(2000); [6]:Parajes, et al. (1941); [7]:Pamir and Ketin (1941); [8]:Barka(1992); [9]:Blumenthal (1945); [10]:Ketin (1948);[11]:Blumenthal (1943); [12]:Tokay (1972); [13]:Ketin (1969); [14]:Öcal (1959); [15]:Ambraseys and Zapotek(1969); [16]:Cisternas et al. (1992); [17]:Demirtaş et al. (1999); [18]:Wright et al. (2001); [19]:USGS (circular 1193); [25] : Bouchon, et al. (2002)

Table-3. The Seismic Moment values calculated for earthquakes studied along the North Anatolian Fault zone

Date	Moment Magnitude (M_W)	Assumed Fault Width W (km)	Seismic Moment M_0(dyne.cm)*10^{26}	References
1939.12.26	7.9	15	41.2	[20]
		12.5	52.0	[3]
1942.12.20	6.9	15	3.2	[20]
		12.5	1.7	[3]
1943.26.11	7.7	15	15.6	[20]
		12.5	29.0	[3]
1944.02.01	7.5	15	23.4	[20]
		12.5	15.0	[3]
1957.05.26	6.8	15	2.37	[20]
		12.5	1.4	[3]
		15	5.6	[20]
1967.07.22	7.0	12.5	2.7	[3]
		-	7.5	[21]
		12.5	0.4	[3]
1992.03.13	6.5	8±4	0.61	[5]
		10±2	1.16	[16]
		-	2.2±0.5	[22]
		9	12	[4]
		15	15.2	[5]
1999.08.17	7.4	-	23.8-25.2-26.5	[18]
		15.9	14	[19]
		17.0	28.8	[23]
		--	25.0	[25]
		14	4.5	[4]
		15	4.6	[5]
		12.6±1.0	6.56±0.34	[18]
1999.11.12	7.1	15.3±1.4	4.17±0.4	[18]
		-	4.5	[19]
		-	6.65	[23]
		12.5	4.7-5.27	[24]

[3]:Stein et al. (1997); [4]:Taymaz (1999); [5]:Irmak (2000); [16]:Cisternas et al. (1992); [18]:Wright et al. (2001) from INSAR data; [19]:USGS (circular 1193); [20]:Ezen (1981); [21]:Taymaz (1991); [22]:Benneth and Toksöz (1992) from GPS data; [23]:Harvard CMTsolutions; [24]:Umutlu (2001); [25] Bouchon et al. (2002)

STRESS – DROP IN THE NORTH ANATOLIAN FAULT ZONE DURING THE 1939-1999 PERIOD

The difference between initial stress (σ_o) and final stress (σ_1) which accompanies a dislocation due to an earthquake is called "stress – drop" $\Delta\sigma = \sigma_o - \sigma_1$.

The stress – drop associated with a shear dislocation can be expressed by

$$\Delta\sigma = \eta.\mu.(U_m / A) \qquad \textbf{(1)}$$

(Aki 1967, Brune and Allen 1967), where $\mathbf{U_m}$ is the maximum relative displacement, η is the rigidity of the elastic medium, **A** is the dimension of the fault plane depending on the type of motion and η is a factor controlled by the geometry of the source. The parameter **A** in **(1)** is the vertical extension of the fault plane for vertical strike slip fault. In case of strike – slip faulting η **= 0.5** is a proper approximation for every case **(Chinnery 1969).** Dislocation is not uniform on a finite fault surface and it decays toward the boundary. For the average dislocation (displacement) $\bar{U}$ was given by **Brune and Allen (1967)** as following form;

$$\bar{U} = 0.75U_m \qquad \textbf{(2)}$$

Finally, assuming that η = **(2/π)** (**Knopoff 1958**) and **A=W** (width of fault plane) and average displacement $\mathbf{\bar{U} = 0.75U_m}$; equation **(1)** becomes

$$\Delta\sigma = (2/\pi).\ \mu.\ (\bar{U} / W) \qquad \textbf{(3)}$$

Kanamori and Anderson (1975). On the other hand substituting seismic Moment Mo **($\mathbf{M_o = \mu \bar{U} S}$)** into equation **(2);** stress – drop can be defined in the following form

$$\Delta\sigma = (2/\pi)\ (Mo / (S.W)) \qquad \textbf{(4)}$$

(Aki 1972). Where **$\Delta\sigma$** is stress – drop (bar), **S** is fault area (S =L. W; L =length of fault, W = width of fault)

Stress – drops for some earthquakes in the North Anatolian Fault zone have been investigated by **Chinnery (1969), Hanks & Wyss (1972), Ezen (1972), Canıtez & Ezen (1973), North (1977), Ezen (1981).**

Ezen (1972) using equation (1) and **Canıtez & Ezen (1973)** using equation (4) and taking W = 20 km, concluded that stress – drop in the North Anatolian Fault Zone is between **10-35** bars for $\mathbf{m_b \geq 7}$ and less than **10** bars for $\mathbf{m_b < 7}$ in 1939-1967 period.

Also**, Ezen (1981)** using equation (4) and assuming W =15 km, concluded that stress – drop in the North Anatolian Fault Zone is between 15-40 bars for Ms ≥ 7 in 1939-1967 period.

In this study , using the seismic Moment (M_o) values are given in **Table 4** and assuming that width of fault plane is W =15 km, we used equation (4) to compute the stress – drop values again for 9 major earthquakes in 1939-1999 period. The stress-drop values are given in **Table 5.** As can be seen in **Table 5**, the stress – drop in the North Anatolian Fault Zone is between 10 and 50 bars.

According to **Aki (1972)** stress – drop associated with shallow earthquakes is 10-100 bar and does not depend on magnitude for $M_s > 6$.

A comparison of seismic moment (M_o) –fault area (S) relation with the theoretical ones obtained from constant stress – drop values (1, 10, 50, 100 bar) are given in **Figure 2**. The values are marked open circles show values are given in **Table 5** with the reference numbered [26].

As is seen in **Figure 2**, the stress drop values calculated for earthquakes related to North Anatolian Fault zone for 1939-1999 period; are between constant stress – drop values with 10 and 50 bars.

These values are very close to other values calculated for earthquakes related to different region of the world **(Aki 1972).**

Table-4. Data base for determination of seismic moment associated with earthquakes along the North Anatolian Fault zone during 1939-1999 period

Date	Moment Magnitude (M_w)	Width of Fault W(km)	Fault Length L(km)	Max. Displacement U_{max}(cm)	Seismic Moment* M_0(dyne. cm)* 10^{26}
1939.12.26	7.9	15	360	370	49.4
1942.12.20	6.9	15	50	175	3.2
1943.11.26	7.7	15	280	250	25.98
1944.02.01	7.5	15	180	350	23.4
1957.05.26	6.8	15	40	160	2.37
1967.07.22	7.0	15	80	190	5.64
1992.03.13	6.5	15	30	95	1.05
1999.08.17	7.4	15	150	450	25.0
1999.11.12	7.1	15	45	420	7.01

* Seismic Moment values are calculated from $M_0 = \mu \bar{U} S$ formula in this calculations.

1) Rigidity module μ was taken as $\mu = 3.3 \times 10^{11}$ CGS Unit(dyne/cm^2)

2) $\overline{U}$ = Avarege displacement, was taken as $\overline{U} = 0.75 * U_{\max}$ [Chinnery 1969],Brune and Allen(1967)

3) Fault Area=S was taken as S=W*L (width of fault*Fault Length); W=Width of fault plane are assumed as 15 km constant value for all eartquakes.

Table-5 Stress-Drop values calculated for earthquakes along to the North Anatolian Fault zone during the 1939-1999 period

Date	Moment Magnitude (M_w)	Width of Fault W(km)	Fault Length L(km)	Fault Area S (km^2)	Seismic Moment* M_0(dyne.cm)*10^{26}	Stress-Drop Δσ (bar)	References
1939.12.26	7.9	15	360	5400	49.4	38.4	[26]
						63.0	[27]
1942.12.20	6.9	15	50	750	3.2	17.8	[26]
						45.0	[27]
1943.11.26	7.7	15	280	4200	25.98	25.9	[26]
						23.0	[27]
1944.02.01	7.5	15	180	2700	23.4	36.3	[26]
						48.0	[27]
1957.05.26	6.8	15	40	600	2.37	16.5	[26]
						24.0	[27]
1967.07.22	7.0	15	80	1200	5.64	19.74	[26]
						90.0	[27]
1992.03.13	6.5	15	30	450	1.05	9.7	[26]
						54.0	[5]
1999.08.17	7.4	15	150	2250	25.0	46.6	[26]
						110.0	[5]
1999.11.12	7.1	15	45	675	7.01	43.5	[26]
						80.0	[5]
						53.0	[24]

[26]: In this study; [27]:North (1977); [5]: Irmak (2000); [24]: Umutlu (2001)

CONCLUSION

The objective of this paper has been to calculate and compare stress – drop values along the North Anatolian Fault zone during the 1939-1999 periods.

The stress – drop values associated with the earthquakes in the North Anatolian Fault zone are not strongly dependent on magnitude. There is no apparent correlation between the "average" stress – drop and the magnitude of the accompanying earthquake.

The calculated stress – drop values for earthquakes with the magnitude Mw>7.0, are between 20 and 50 bars, for smaller earthquakes (Mw<7.0) we found less than 20 bars.

The total stress – drop in the area is between 10 and 50 bars. However there are some low stress–drop areas in the fault zone due to either strain accumulation or creep phenomenon.

However, in the present author's opinion, there is a definite limit to the amount of complexity for stress – drop values. The reason for this is the general lack of adequate observational field data for studied earthquakes.

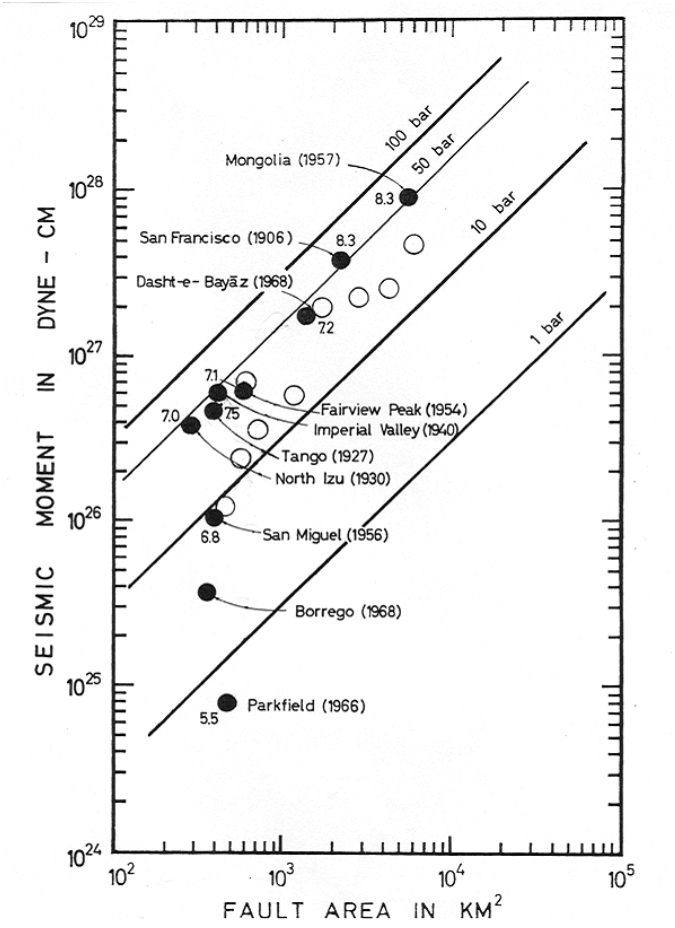

Figure-2. A comparison of seismic moment-fault area relation with the theoretical ones obtained from constant stress-drop values approximation (after Aki, 1972) Open circles show stress-drop values, which are calculated in this study, are given in table 5 with the reference numbered [26]

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