SEISMOTECTONICS OF THE SOUTHERN MARMARA REGION, NW TURKEY

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Abstract

The Southern Marmara Region is an active deformation area, which is a transition zone between the strike-slip tectonics manifested by the North Anatolian Fault System and the N-S extensional regime of the Aegean Region.

We have reviewed tectonic and geological structure of the region, based on seismological studies. We have obtained a total of 37 earthquake moment tensor solutions between 1953 and 2015. In addition, stress tensor analysis has been carried out using 37 earthquake moment tensor solutions. Also long term seismicity were investigated and a,b, Mc values were calculated and mapped. Moment tensor solutions indicate that the source of these earthquakes are mostly NE-trending dextral strike-slip faults and some of them are E-W trending dip-slip normal faults. The stress tensor analysis shows that the direction of the regional compressive stress is NW-SE.

The temporal and spatial distrubution of the large earthquakes (1944, 1953, 1964) indicate that the ruptures unilaterally propagate from SW to NE. The 1855 earthquake had been occurred to the east of Manyas Lake. The elapsed time (160 year) and regional stress transfer suggest that the segments to the east of Manyas Lake form a probable seismic gap and this area has a high earthquake risk.

Keywords: *Moment Tensor Solution, Stress Tensor Analysis, b value, North Anatolian Fault, Southern Marmara Region, Aegean Region.*

1. Introduction

The active deformation in the eastern Mediterranean region is closely associated with the Aegean and Cyprean subduction zones and the continental collision that is taking place between the African-Arabian and the Eurasian plates. As a result, active tectonics of the eastern Mediterranean region is mainly controlled by the dextral North Anatolian Fault System (NAFS) and the sinistral East Anatolian Fault System (EAFS), The Dead Sea Fault Zone (DSFZ) and the Aegean and Cyprean Subduction Zones.

The NAFS is a major active dextral strike-slip fault system in the eastern Mediterranean region. It extends from the Karlıova triple junction in eastern Turkey to the Gulf of Saros in the North Aegean Sea for an approximately 1200 km (Barka and Gülen, 1988 and Şengör *et al.,* 2004) (Figure 1). The NAFS continues across the northern Aegean Sea, and it crosses central mainland Greece as a broad shear zone (termed the Gracian Shear Zone by Şengör, 1979) and it eventually links up with the Aegean Arc (Dewey and Şengör, 1979; Le Pichon *et al.,* 1993; McKenzie and Jackson, 1983 and Şengör *et al.,* 2004). The NAFS bifurcates into three strands just to the east of Sakarya, around the

Mudurnu valley, forming a horse-tail structure (Barka and Gülen, 1988 and Barka, 1992) (Figure 1). The northern strand starts from the south-east of Sapanca Lake and it passes through the Marmara Sea, Gulf of Saros and the North Aegean Trough (Lyberis, 1984 and Kürçer *et al.*, 2015). The central strand follows the path through Geyve basin, Pamukova, South of İznik Lake, southern coast of Marmara Sea and Bandırma, where it makes a restraining bend and continues south-west in the Biga Peninsula (Kürçer *et al*., 2015). The central strand of NAFS consists of several dextral strike-slip fault segments in the Biga Peninsula. The southern strand of NAFS consists of the Bursa Fault, the Uluabat Fault, the Manyas Fault, the Yenice Gönen Fault, the Evciler Fault and the Edremit Fault in Biga Peninsula and it extends towards the Skyros Basin in the Aegean Sea (Figure 1). The deformation of the Southern Marmara Region is mainly controlled by the middle and southern strands of the NAFS and the Aegean Extensional Regime. The seismotectonic characteristics of the Southern Marmara Region and its vicinity have been studied by several authors (see Üçer *et al*., 1997; Nalbant *et al.*, 1998; Gürbüz *et al*., 2000; Gürer *et al.*, 2003 and 2006 and Kürçer *et al.,* 2015). Neotectonic and paleoseismological studies on several segments of the middle and southern strand of the NAFS produced new data about the kinematic characteristics and the time record of major earthquakes (Kürçer *et al.,* 2008). The GPS measurements show that relative displacement of Anatolia with respect to Eurasia is mainly accomodated by the northern strand of the NAFS (Straub and Kahle, 1994, 1995; Barka and Reilinger, 1997; Meade *et al.*, 2002; Kreemer *et al.*, 2004 and Reilinger *et al*., 2006). The two other strands of the NAFS are less active with respect to the northern strand. Meade *et al.* (2002) suggest 6.8 ± 2.3 mm/yr and similarly, Kreemer *et al.* (2004) suggest 7 mm/yr strike-slip rates for these middle and southern strands of the NAFZ. Many destructive and moderate earthquakes have occurred in the southern Marmara region during both historical and instrumental periods. Some of these are the October 6, 1944 Gulf of Edremit - Ayvacık earthquake (Ms=6.8; Ambraseys, 1988), the March 18, 1953 Yenice-Gönen earthquake (Ms=7.2; McKenzie, 1972), the October 6, 1964 Manyas earthquake (Ms=6.9; Taymaz *et al.,* 1991). Many destructive historical earthquakes had occured in this area such as AD. 123, 160, 368, 1855 (Ambraseys, 2002), AD. 1737 and 1850 (Ambraseys and Jackson, 2000), AD. 155, 543, 1323 (Ambraseys and Finkel, 1991).

This study is mainly concerned with the interactions between earthquakes that occured in the region and temporal and spatial distribution of these events. The aim of this paper is to better understand the geometric and kinematic features of the faults in the Southern Marmara Region. The current state of stress of the regional crust has been investigated and the results are discussed in the context of regional tectonic setting and seismic hazard assessment.

2. Moment Tensor Solution, Stress Tensor Analysis and b value analysis

In this study a regional seismic source model has been prepared using an updated active fault database, instrumental and historical earthquake database for the study area. The instrumental earthquake near field wave forms were obtained from the Kandilli Observatory and Earthquake Research Institute Regional Earthquake-Tsunami Monitoring Center (KOERI-RETMC). Firstly, source parameters of 30 events that have magnitudes Mw ≥ 3.3 have been modelled by seismic moment tensor inversion developed by Sokos and Zahradnik (2006) algorithm (Figure 2). Secondly, stress tensor inversions have been carried out using the Micheal (1987) method. The results of the moment tensor solutions for earthquakes with moment magnitude greater than Mw>1.9 (Table 1) were inverted to obtain stress tensors and they were mapped (Figure 3). Orientation of the σ1, σ2, and σ3 were computed and the principal stress axes are projected onto a lower hemisphere Wulff net. The shape factor (R) was calculated by using the focal mechanism solutions for the seismogenic zone.

The results of regional stress tensor analysis for the shape and orientation of the stress tensors calculated from the obtained 37 fault plane solutions (Figure 2). The principal directions are projected onto a lower hemisphere Wulff net. The white rectangle, green triangles and purple circles indicate the azimuths and plunges of the maximum compression axis σ1, the intermediate stress axis σ2 and the minimum stress axis σ3.

Figure 1 - Active faults in the western Turkey, northern Aegean Sea and northern Greece (active faults were compiled from the following references; in mainland Turkey: Emre *et al.* (2013) and the references included therein; Troy area: Kürçer *et al.* (2012); South-west Marmara Sea: Yaltirak (2002); Çanakkale Strait: Gökaşan *et al.* (2008); active faults at the western part of Gulf of Edremit and its vicinity: Yaltirak *et al.* (2012); North-eastern Greece: Pavlides *et al.* (2007); Agios Efstratios fault: Chatzipetros *et al.* (2012); active faults near Bozcaada: Kürçer *et al.* (2015).

Figure 2 - Focal mechanisms and MT solutions compiled and obtained respectively in the study for the region. The numbers in the map and near the mechanisms indicate earthquake numbers in Table 1 which also contain source parameters.

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The best fit was attained for Phi = 0.75+/ −0.12964 that indicates that the stress regime is strike slip with azimuth and plunge pair of (-72.5°, 19.9°) for σ1, (142.3°, 66.2°) for σ2 and (22.1°, 12.5°) for σ3, respectively (Figure 3a).The stress tensor analysis of studied earthquakes in the region indicates that the region has predominantly strike-slip faulting with a minor normal component (Figure 3). These results indicate the presence of a transtensional tectonic regime in the southern Marmara region.

Thirdly, an instrumental earthquake catalog was prepared for the seismogenic zone using the seismic database of KOERI-RETMC. Aftershocks, foreshocks and earthquake swarms are removed using the declustering algorithm of Reasenberg (1985). As a result of declustering a total of 1357 events that form 402 clusters were removed from the dataset. Gutenberg and Richter (1944) parameters (a and b values) were calculated for the seismic source. b value is a constant parameter which has been shown to be inversely related to the stress in the crust (Wiemer and Wyss, 1997), and the a value is a function of earthquake activity rate of the crust, size of the region, and observation time (Kalafat *et al.,* 2013). Especially, the time distribution histogram of the catalog indicates that the seismic catalog is complete for which magnitude Mc=2.9 since 1983 for the seismogenic zone. Therefore, the KOERI catalog was re-analysed for the period between 1983-2015. Based on the maximum likelihood solution; we obtained b= 1.29+/-0.1 and a= 7.3.
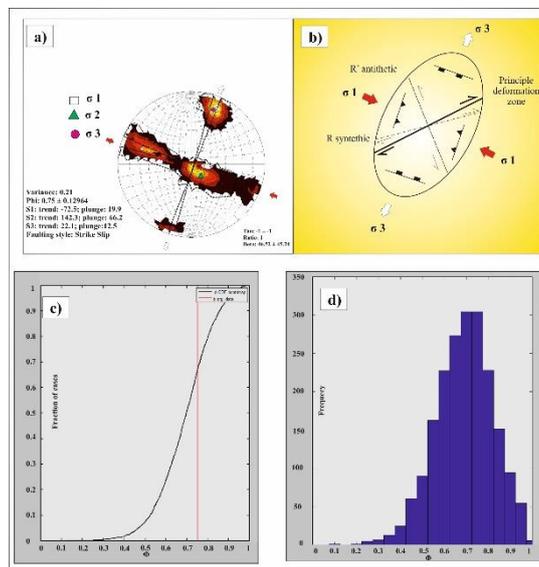

Figure 3 - a) The result of regional stress tensor analysis for the shape and orientation of the stress tensor calculated from compiled and the obtained 37 fault plane solutions given in Table 1 a) The white rectangle, green triangles and purple circles indicate the azimuths and plunges of the maximum compression axis σ1, the minimum stress axis σ3 and the intermediate stress axis σ2. The best fit was attained for Phi = 0.75+/ −0.12964 that indicates that the stress regime is strike slip with azimuth and plunge pair of (-72.5°, 19.9°) for σ1, (142.3°, 66.2°) for σ2 and (22.1°, 12.5°) for σ3, respectively b) Strain ellipsoid for a dextral strike-slip fault (Principle deformation zone), the positions of the sigma 1 and sigma 3 principal axes of stress, and the R and R' orientations c) The plot of stress ratio relative to fraction cases d) The histogram of R-value. Note that the inversion result indicates a strike-slip regime with minor normal component that has a relative stress magnitude of between 0.5 and 1.

The variation of b values has been mapped. a - b values and completeness magnitude have been computed using the maximum likelihood method (Aki, 1965) and Wiemer (2001) algorithm. Based on the maximum likelihood solution; The variance of b value changes in the range of 0.5-1.40 within the seismogenic zone in the southern Marmara (Figure 4).

Table 1- Source parameters of the earthquakes used in the study (References: 1- McKenzie, 1972; 2- Taymaz *et al.,* 1991; 3- Papadopoulos *et al.,* 1986; 4- Harvard Univ., 1998; 5- This study; 6- Altuncu Poyraz *et al.,* 2015; 7-Altınok *et al.,* 2012).

No	Lon	Lat	Year	M	Day	Mw	Depth	Str.	Dip	Rake	Ref
1	27.49	40.01	1953	3	18	7.2	40	59	76	174	1
2	28.20	40.20	1964	10	6	6.9	14	100	40	-90	2
3	27.50	40.08	1969	3	3	5.7	4	219	65	45	1
4	27.32	39.62	1971	2	23	5.6	10	86	66	160	3
5	27.21	40.33	1983	7	5	6.1	15	254	49	-173	4
6	25.86	39.34	2006	4	24	4.0	6	146	44	86	5
7	25.76	39.50	2007	1	8	3.4	16	44	87	166	5
8	27.07	40.14	2014	12	16	4.2	2	252	77	-173	5
9	26.92	39.37	2005	8	3	3.8	8	59	65	-162	5
10	25.84	39.55	2007	1	8	4.0	4	77	55	-116	5
11	29.96	40.18	2011	7	11	5.0	5	103	73	80	5
12	27.03	40.24	2012	1	12	3.3	15	154	31	-126	5
13	26.11	39.78	2014	1	7	3.7	8	304	36	-70	5
14	26.13	39.79	2014	1	13	3.8	10	235	65	177	5
15	26.32	39.40	2015	1	19	4.1	33	308	63	-114	5
16	29.13	40.41	2015	5	11	4.3	5	134	74	166	5
17	25.80	39.89	2009	6	23	3.6	24	257	65	-144	5
18	27.18	39.94	2009	3	29	3.5	4	94	68	178	5
19	27.85	39.66	2015	3	18	3.8	16	327	28	-106	5
20	28.58	40.06	2015	1	23	4.2	12	127	83	29	5
21	29.16	40.62	2014	8	3	3.9	5	82	36	-92	5
22	30.11	40.40	2014	10	22	4.0	5	59	52	179	5
23	25.60	39.68	2013	1	9	4.0	4	237	70	-159	5
24	27.93	40.21	2014	7	3	4.2	12	78	88	166	5
25	27.83	39.68	2015	7	2	4.2	7	215	57	100	5
26	27.98	40.26	2006	10	20	4.2	5	70	82	-141	5
27	29.00	40.44	2006	10	25	3.7	11	268	62	-104	5
28	27.86	39.67	2015	6	30	3.6	17	250	37	-43	5
29	27.85	39.69	2015	7	2	3.9	5	221	50	103	5
30	30.29	40.31	1999	9	13	5.8	15	176	86	-31	4
31	29.95	40.15	2011	7	11	4.6	6	105	77	-66	6
32	30.14	40.48	2012	6	28	2.1	6.8	77	88	163	6
33	30.04	40.45	2012	7	10	2.6	9.4	236	83	175	6
34	30.16	40.39	2013	1	23	2.6	1.8	53	89	-172	6
35	30.54	40.57	2013	3	7	2.5	5.2	11	68	-151	6
36	30.48	40.52	2013	4	13	1.9	6.9	354	79	11	6
37	39.45	26.52	1944	10	6	6.7	*	*	*	*	7
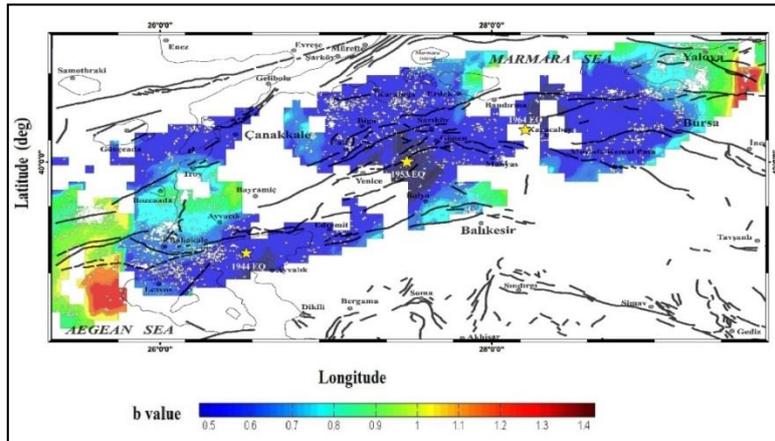
Figure 4 - Map view of spatial distribution of b values using the best combination maximum likelihood method for the time period between 1905-2015 instrumental catalog. The number of earthquakes per sample is 50, the nodal separation is 0.025°, and the radius of the cylindrical sample volumes is R≥20 km.

3. Discussion and Conclusion

In this study, source parameters of the southern Marmara region earthquakes are investigated using the seismic moment tensor method. The sources of southern Marmara Region earthquakes are mainly NE-SW trending dextral strike-slip faults and to a lesser extend E-W normal faults based on the earthquake moment tensor solutions and spatial distribution of the earthquake epicenters. The stress tensor inversions are analysed using focal mechanism solutions and fault groups using a total of 37 earthquakes (Table 1 and Figure 3). We have obtained the three principle stresses ($\sigma 1$, $\sigma 2$ and $\sigma 3$) and their relative size and uniformity of stress field variations for the all events in the studied region. Stress tensor results indicate a strike-slip tectonic regime with minor normal component in the southern Marmara region. The 1944 Gulf of Edremit - Ayvacık and 1964 Manyas earthquakes were occurred on oblique faults that have major normal and minor right lateral strike slip component. The b value varies in the range of 0.5 to 1.4 for the time period between 1905-2015 for the seismic source zone. Although the segments in the southwestern and northeastern tips of the study area have high b values around 1.1- 1.4, the central segments have very low b values around 0.5 – 0.8 (Figure 4). The highest b values were observed on the offshore fault segments (near the Lesvos island), so we may conclude that a major energy release had occurred during the devastating 1944 Gulf of Edremit – Ayvacık earthquake. Apparently, after the October 6, 1944 Gulf of Edremit-Ayvacık earthquake (Mw=6.7), stress had been transferred to the 1953 earthquake segment in the NW. Similarly, after the March 18, 1953 Yenice – Gönen earthquake (Mw=7.2), stress had been transferred to the October 6, 1964 Manyas earthquake (Mw=6.9) earthquake segment to the east. These earthquakes and recent earthquakes to the east of Manyas Lake region indicate that there is a big earthquake hazard potential. The spatial and temporal distribution of these earthquakes indicates that the surface ruptures unilaterally propogate from SW to NE. The 1855 earthquake had been occurred to the east of Manyas Lake. The elapsed time of 160 years and the regional stress transfer point out that the segments at the east of Manyas Lake may represent a probable seismic gap and a potential earthquake hazard for this region.

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