SOURCE PARAMETERS OF MODERATE AND STRONG EARTHQUAKES FOR TURKEY AND ITS SURROUNDING AREA (1938-2017)

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Summary. The main goal of this study is calculating earthquake source parameters with inversion technique and preparing focal mechanism – moment tensor – faulting types data bank of Turkey and surrounding area and performing regional stress analysis. Source parameters–faulting mechanisms occurred in Turkey and surrounding area, compiling them and collecting in a complete data base in order to present the researchers attention from the date which the instrumental seismology started of 1938 until these days, consist the main work package of this research. This research was aimed to complete the previously made researches and updating of them. Approximately 70% of the fault parameters of all earthquakes were calculated within the scope of this study. Homogeneous and integrated data set preparation by calculating all missing parameters belonging to previous earthquakes was aimed within the scope of research. We used fault parameters such as strike, dip, rake, seismic moment, moment magnitude, P and T axes azimuths and plunges for each earthquake. We prepared regional faulting types maps at regions belonging different tectonic regimes in Turkey by using faulting parameters. In this context, a total of 1950 earthquakes ($M_w \geq 4.0$) source parameters and fault plane solutions have been compiled and a large part of them have been calculated within the scope of the study.

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1. Introduction

Turkey is located in the eastern Mediterranean sector of the Alpine-Himalayan orogenic belt. This area comprises the technically most active in the Mediterranean region, because the country is located at the junction of the main tectonic plates, namely, African, Arabian and Eurasian (McKenzie, 1978; Dewey and Şengör, 1979; Barka and Kandinsky-Cade, 1988; Şengör et al., 1983). Global kinematic models based on the analysis of oceanic spreading, fault system, and earthquake slip vectors indicate that Arabian plate is moving in the north-northwest direction relative to Eurasian at an average rate of about 20-30 mm/yr (Reilinger et al., 2006). Turkey is escaping from Eastern Anatolia due to collision between Arabia and Eurasian, and trust over the African oceanic plate along the Hellenic arc. The motion is taken up by strike-slip deformation along the North Anatolian and East Anatolian faults (Fig. 1).

As a consequence of the above condition the direct impact to this country leads to continuous earthquake events. According to the statistics,

over 15.000 earthquakes occur per year in Turkey (Fig. 1). An important part of these earthquakes is felt by people. This requires quick information about the earthquake, especially earthquake source parameters, specific fault type and moment magnitude.

Source parameters – faulting mechanisms occurred in Turkey and surrounding area, compiling them and collecting in a complete data base in order to present the researchers attention from the date which the instrumental seismology started of 1938 until these days, consist the main work package of this research. Many researches have been carried out internationally (Alptekin, 1973; Alptekin et al., 1985; Alsan et al., 1984; Büyükaşkoğlu, 1979; Canitez and Büyükaşkoğlu, 1984; Canitez and Toksöz, 1971; Canitez and Üçer 1967; Comninakis and Papazachos, 1972; Eyidoğan, 1983, 1992; Eyidoğan et al., 1986; Eyidoğan and Jackson, 1985; Jackson and McKenzie, 1984; Kalafat, 1988, 1989, 1998, 2016; Kalafat et al., 2009; Kocafe and Ataman, 1976; Mercier et al., 1973; McKenzie, 1972, 1978; Nowroozi, 1972; Öcal, 1960; Öcal et al., 1968; Pınar and Kalafat, 1999; Pınar and Honkura,

Fig. 1. Seismicity and important earthquakes ($M_s > 7.0$) that occurred in the region during 1900-2017 (yellow stars symbols indicate magnitude $M_s > 7.0$ earthquakes)

1994; Pacheco et al., 1989; Stewart and Kanamori, 1982; Taymaz et al., 1991a,b; Taymaz, 1993), because of the subject is one of main problems of seismology. Increasing the station and data quality accordingly, detailed studies have been performed about the subject related to the data process and developing analyze methods. A computational complete data base hasn't been generated about the subject until these days in Turkey. But only fault mechanism solutions of one or more earthquake have been carried out by scientific articles and thesis. For that reason calculating fault-source parameters of earthquakes ($M_w \geq 4.0$) from 1938 until these days and gathering this information in an integrated structure to present the attention of researchers constitute the essential purposes of this research. This research was aimed to complete the previously made researches and updating of them. Homogenous and integrated data set preparation by calculating all missing parameters belonging to previous earthquakes was aimed within the scope of research.

2. Data and Methods

The previously performed mechanism analyses of the earthquakes occurring in the region – generally as $M \geq 4.0$ have been compiled and the missing ones were solved. Kandilli Observatory and Earthquake

Research Institute (KOERI) had started to establish countrywide broadband earthquake stations especially as from 2004. In Turkey the first earthquake station with satellite connection had been established in August 2004 (Kalafat et al., 2005). Thus the analyses of earthquakes arising until 2004 had been obtained by assessing analogous records. And after 2004 the records of digital broadband stations had been used. Especially after 2004 the moment tensor analyses of earthquakes have been performed with sufficient number of digital waveform.

In this context, the instrumental period of about 1950 earthquake faulting solutions since 1938 compiled under this study and about 70% earthquakes CMT solutions have been done in the region after 2004 under this study.

Three separate methods were used in the study. These were as follows:

1. FOCMEC (Snoke, 2003)
2. TDMT_INV Technique (Dreger, 2002)
3. Isola (Sokos and Zaharadnik, 2013).

In this study we don't provide detailed information about using programs.

We used regionally recorded broad-band velocity waveforms for CMT solutions. We calculated usually moment tensors of the magnitude bigger

$M_w \geq 4.0$ earthquakes. Moment Tensor Inversion Technique (TDMT_INV time-domain inversion code Dreger, 2002; Sokos and Zaharadnik, 2013) was used for the earthquakes recorded by at least 3 digital broadband seismic stations of KOERI and other neighbor seismological networks with 3-component recordings filtered by a band-pass filters described below. The quality (good signal-to-noise ratio) of the available data allowed the computation of earthquake focal mechanisms and source depths. Green's functions were calculated using the frequency-wave number integration code (FKRPROG) developed by Saikia (1994).

Once we have the location and magnitude of an event we can proceed on CMT estimation following the two stages given below:

- Data preparation for inversion
- CMT Inversion process.

In the first stage, the three component digital broadband waveforms are cut according to the origin time, station response is removed, the horizontal components are rotated to get the radial and transversal components, integration or derivation is applied depending on the data type to get the displacements in cm. The modeling process is carried out using the long periods of the seismograms where the frequency range depends on the magnitude of the event. We apply the following frequency ranges for different magnitude ranges:

$M < 4$	0.02 - 0.1 Hz,
$4.0 \leq M < 5.0$	0.02 - 0.05 Hz,
$5.0 \leq M < 7.5$	0.01 - 0.05 Hz,
$M \geq 7.5$	0.005 - 0.05 Hz.

The sampling rate of the observed and the calculated seismograms are modified to have the same

sampling rate. Commonly 1-D velocity model used to locate the earthquakes in Turkey (Kalafat et al., 1987). We calculated moment tensors of the mainshocks and their strong aftershocks (Fig. 2, Fig. 3). A sample page from the catalog prepared within the scope of the study is given in Table.

3. Conclusion

The complete characterization of earthquakes focal mechanisms provide important information for scientists and especially structural geologist working on active structures. This information is including the origin time, epicenter location, focal depth, seismic moment, the moment magnitude and spatial orientation of the 9 components of the moment tensor. And from the moment tensor we can ultimately resolve the orientation and sense of slip of the fault.

Within the scope of this study we calculated moment tensor solutions of important earthquakes in Turkey and surrounding area. We used MT catalog which scope of this work, and prepared a general type of faulting type map for Turkey and surrounding area. This map puts forth that in general so many different tectonic regimes have been still continuing in Turkey today (Fig. 4).

Current catalogue data were obtained by using general stress analysis (Gephart, 1990) by taking 7 main tectonic units that was previously determined (Fig. 5).

A brief evaluation of the stress analysis findings with respect to regions manifests that:

1st Region (NW Turkey – Marmara Region): Mechanism solutions exhibit that within NW Turkey and Marmara region strike slip and normal component oblique faults are widely effective. In this region P-axis directions are generally NW-SE extended.

Fig. 2. Examples of inversion (used Dreger, 2002 TDMT_INV code)

Fig. 3. Moment tensor solutions of earthquakes ($M_w \geq 4.0$) that occurred during 1938-2017 in Turkey and surrounding area

Fig. 4. Moment tensor solutions of earthquakes ($M_w \geq 6.0$) that occurred during 1938-2017 in Turkey and surrounding area and main faulting types in the regions

Table

An Example of source parameters catalogue (1938-2017)

Eq. No.	Date D/M/Y	O. Time (UTC)	Lat. N (°)	Lon. E (°)	Depth (km)	Mag. (Mw)	Seismic moment (nm)	FAULT Parameters							Region	Source. No.
								Strike	Dip	Rake	P axis Azm.	P axis Plung	T axis Azm.	T axis Plung		
								Deg.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.		
1	14.09.2015	09:07	43.32	41.11	31.0	4.9	2.66E+16	106.0	88.0	-1.0	61.0	2.0	331.0	0.0	Georgia	This Study
2	15.09.2015	05:04	34.77	24.99	6.0	4.2	2.41E+15	53.0	56.0	-88.0	330.4	78.9	141.6	11.0	Crete-Greece-Mediterranean Sea	NOA
3	16.09.2015	19:12	38.56	44.56	10.0	4.3	3.13E+15	90.0	86.0	-168.0	315.0	11.0	224.0	5.0	Eastern Turkey-Turkey-Iran Border Region	This Study
4	16.09.2015	19:52	35.89	27.83	37.0	4.9	2.63E+16	167.0	63.0	1.0	125.0	18.0	28.0	20.0	Mediterranean Sea	This Study
5	22.09.2015	06:25	39.15	29.13	12.0	4.0	1.12E+15	318.0	59.0	-76.0	262.0	72.0	38.0	13.0	Simav-Kütahya-Western Turkey	This Study
6	22.09.2015	07:11	39.15	29.13	14.0	4.0	1.18E+15	252.0	63.0	-111.0	124.0	66.0	357.0	15.0	Simav-Kütahya-Western Turkey	This Study
7	29.09.2015	09:12	34.69	24.59	34.0	4.4	4.35E+15	273.0	79.0	-80.0	195.3	54.9	-5.4	33.3	Crete-Greece-Mediterranean Sea	NOA
8	03.10.2015	21:08	38.18	38.93	14.0	4.0	1.40E+15	155.0	73.0	-170.0	17.0	19.0	109.0	5.0	Puturge-Malatya-Eastern Turkey	This Study
9	06.10.2015	21:27	36.15	29.89	38.0	5.2	6.73E+16	291.0	31.0	-132.0	100.0	61.0	231.0	20.0	Demre-Antalya-Southern Turkey	This Study
10	09.10.2015	14:39	40.67	36.68	11.0	4.7	1.61E+16	278.0	82.0	172.0	324.0	0.0	234.0	12.0	Tepekişla-Erbaa-Tokat-NAF	This Study
11	12.10.2015	02:16	34.54	26.50	16.0	4.6	9.82E+15	323.0	66.0	-153.0	182.0	36.0	91.0	1.0	Offshore Crete Island-Mediterranean Sea	This Study
12	13.10.2015	23:18	39.15	29.05	10.0	4.0	1.22E+15	287.0	56.0	-96.0	174.0	78.0	21.0	11.0	Simav-Kütahya-Western Turkey	This Study
13	24.10.2015	02:59	35.32	23.25	38.0	4.1	1.50E+15	115.0	54.0	92.0	203.6	9.0	34.0	80.9	Crete-Greece-Mediterranean Sea	NOA
14	27.10.2015	01:25	38.94	24.36	11.0	4.5	6.29E+15	245.0	78.0	-129.0	118.0	43.0	4.0	23.0	Aegean Sea	This Study
15	28.10.2015	16:20	40.80	27.76	15.0	4.5	6.97E+15	248.0	81.0	165.0	295.0	4.0	203.0	17.0	Marmara Sea	This Study
16	29.10.2015	09:46	39.11	43.73	12.0	4.5	1.17E+16	109.0	53.0	149.0	341.0	8.0	79.0	45.0	Muradiye-Van-Eastern Turkey	This Study
17	18.11.2015	14:55	38.86	29.32	21.0	4.3	3.77E+15	152.0	61.0	-179.0	13.0	21.0	111.0	19.0	Honaz-Denizli-Western Turkey	This Study
18	29.11.2015	00:28	38.82	37.84	10.0	4.9	2.40E+16	160.0	90.0	-157.0	27.0	16.0	292.0	16.0	Hekimhan-Malatya-Eastern Turkey	This Study
19	02.12.2015	23:27	39.28	40.24	10.0	5.2	7.03E+16	217.0	63.0	-17.0	179.0	30.0	85.0	7.0	Kığı-Bingöl-Eastern Turkey	This Study

(NOA :National Observatory of Athens, Greece)

Fig. 5. The Regional stress tensor analysis: Regional main stress (P and T) directions (red arrows indicate maximum tensional, brown bars indicate main directions of maximum pressure)

2nd Region (North Anatolian Fault Zone – NAFZ): Strike slip faults are widely effective and dominant P-axis directions are NW-SE extended in North Anatolia Fault Zone.

3rd Region (Western Turkey): In Western Turkey extension regime is heavily dominant and normal faults are equally dominant. Dominant P-axis directions are W-SW/-E-NE extended on a large scale.

4th Region (Eastern Anatolian Fault Zone – EAFZ): In Eastern Anatolia Fault Zone strike slip faults are dominant and P-axis directions are NE-SW extended generally.

5th Region (Central Anatolia): In Central Anatolia Region normal faults are widely dominant. In addition there are some oblique faults that have strike-slip component. In this region too P-axis directions are generally E-W extended.

6th Region (Northeastern Turkey): Mechanism solutions in Northeast Anatolia Region reveal that strike slip faults are widely dominant. In this region P-axe

strikes are usually concentrated on N-NW-S-SE route.

7th Region (Southeast Turkey): In Southeast Turkey Region a compression-shortening regime is dominant. On a general scale thrust faults are dominant however strike-slip faults and oblique faults with strike-slip components are also widely present. P-axis directions are mostly concentrated NNW-SSE trending.

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ИСХОДНЫЕ ПАРАМЕТРЫ СРЕДНИХ И СИЛЬНЫХ ЗЕМЛЕТРЯСЕНИЙ В ТУРЦИИ И ПРИЛЕГАЮЩИХ К НЕЙ РАЙОНАХ (1938-2017 гг.)

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Резюме. Главной целью исследования являются вычисление параметров очагов землетрясений с помощью метода инверсии, подготовка банка типов тектонических нарушений на территории Турции и прилегающих районов согласно фокальному механизму и тензору сейсмического момента, а также расчет региональных напряжений. Основной задачей является сбор исходных параметров – механизмов тектонических нарушений, произошедших в Турции и прилегающих районах, в полную базу данных. Эта работа проводилась с намерением пополнить и обновить ранее проведенные исследования. Надо отметить, что в Турции инструментальная сейсмология применяется с 1938 года. Приблизительно 70% параметров тектонических нарушений были вычислены в рамках данного исследования. Статья также посвящена подготовке базы однородных и комплексных данных путем расчета всех недостающих параметров ранее произошедших землетрясений. Подготовлена карта региональных типов тектонических нарушений с помощью набора тензора сейсмического момента, расчета региональных напряжений и осевых ориентаций в регионах Турции, относящихся к различным тектоническим режимам, используя параметры каждого землетрясения (направление, простирание, угол наклона, сейсмический момент M_0 , моментная магнитуда M_w , оси Р и Т азимута сжатия и растяжения). В итоге в статье обобщены параметры очагов 1950 землетрясений ($M_w \geq 4.0$) и решений плоскости тектонического нарушения, причем большая их часть рассчитана в этом исследовании.

Ключевые слова: фокальный механизм, Турция, тензор сейсмического момента, параметры очагов, моментная магнитуда

TÜRKİYƏDƏ VƏ BİTİŞİK RAYONLARDA ORTA VƏ GÜCLÜ ZƏLZƏLƏLƏRİN BAŞLANGIC PARAMETRLƏRİ (1938-2017-Cİ İLLƏR)

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Xülasə. Tədqiqatın başlıca məqsədi inversiya metodunun köməyi ilə zəlzələ ocaqlarının parametrlərinin hesablanması, seysmik momentin fokus mexanizminə və tenzoruna müvafiq olaraq Türkiyə ərazisində və bitişik rayonlarda tektonik pozulmaların tiplərinin bankının hazırlanmasından, həmçinin regional gərginliklərin hesablanmasından ibarətdir. İşin əsas vəzifəsi başlangıç parametrlərinin – Türkiyədə və bitişik rayonlarda baş vermiş tektonik pozulmaların mexanizmlərinin – məlumatların bütöv bazasına toplanmasından ibarətdir və bu da tədqiqatçıların diqqətinə çatdırmaq məqsədi daşıyır ki, instrumental seysmologiya 1938-ci ildən tətbiq edilməyə başlanmışdır və bu gün də istifadə olunur. Bu iş əvvəllər aparılmış tədqiqatların təzələnməsi və təkmilləşdirilməsi məqsədilə aparılmışdır. Tektonik pozulmaların parametrlərinin təxminən 70%-i bu tədqiqatın çərçivəsində hesablanmışdır. Məqalə həmçinin əvvəllər baş vermiş zəlzələlərin bütün çatışmayan parametrlərinin hesablanması yolu ilə həmcinsli və kompleks məlumatların bazasının hazırlanmasına həsr edilmişdir. Hər bir zəlzələnin parametrlərindən (istiqlal, uzanma, əyilmə meyli, seysmik moment M_0 , zaman məqnitudası M_w , sıxılma və gərginlik azimutunun P və T oxları) istifadə etməklə Türkiyənin regionlarında regional gərginliklərin və ox istiqamətlərinin hesablanmasının, seysmik momentin tenzor dəstinin köməyi ilə tektonik pozulmaların regional tiplərinin xəritəsi hazırlanmışdır. Nəticədə məqalədə 1950 zəlzələ ocaqlarının ($M_w \geq 4.0$) parametrləri və tektonik pozulma müstəvisinin həlli ümumi-ləşdirilmişdir.

Açar sözlər: fokus mexanizmi, Türkiyə, seysmik momentin tenzoru, ocaqların parametrləri, moment məqnitudası