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Earthquake Moment Tensor Analysis Using Broadband Seismic Waveforms

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Abstract

In this study the focal mechanisms are determined for the broadband waveforms of the earthquakes occurred in Kurdistan region, NE-Iraq and west of Zagros Mountains which are recorded by Sulaimani and Duhok University Observatories and Observatory and Earthquake Research Institute using moment tensor analysis. The seismic moment, depth and the nature of responsible fault that ruptured at the source are calculated by the waveform inversion. The inversion technique used is a grid search over the strike, dip and rake angles for each depth from 0.5 to 39 km in increments of 1 km. The observed and predicted waveforms are filtered and compared using bandpass filters and a proper velocity model for the Green's function. The mechanism to the best fit was determined and the regional stresses was characterized in the study area. The results indicate a combination of mostly strike-slip with some dip-slip and oblique-slip motion.

Introduction

The study area is located at the northeastern part of Iraq, within Kurdistan region, nearly the thrust and folded zone which is at the northeastern edge of the Arabian plate (Figure: 1). The Arabian Plate is surrounded by regions of relatively high seismicity. The seismicity is important for seismic hazard and risk assessments [2]. The goal of this investigation is to obtain the focal mechanism solutions for the earthquakes occurred in this area which are derived from a solution of the moment tensor and analysis of observed seismic waveforms. Study of these events will help in understanding of seismic hazard [3]. Seismograms reflect the combined influence of the seismic source [4]. The focal mechanism of an earthquake describes the deformation within the area that that generates the seismic waves. In a global scale, the majority of the strain area can be estimated by using earthquake focal technique [5]. The pattern of energy radiation generated by earthquakes and other sources such as explosions is quite different [6].

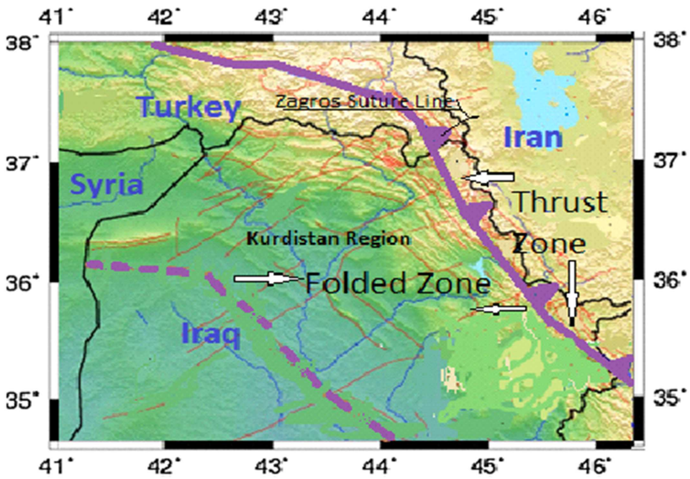

Figure-1: Map of the studied area

Seismotectonics setting

The seismicity of Iraq has shown a relation with the overall orientation of the seismicity of the Bitlis, Zagros Fold and Thrust Belt. Its seismic activity is moderate to high at northern and northeastern parts of it. Generally, the tectonics of the study area is controlled by the collision of the Arabian and Iranian plates [8]. This seismicity was the result of reverse faulting nearly parallel to the seismic trends of the Zagros-Taurus belts [1].

Focal Mechanism Solutions and Waveform Inversion

A focal mechanism solution (FMS) is the analysis of the fault surface on which an earthquake took place and produced seismic wave signal. The fault plane can be distinguished from the auxiliary plane based on geological field and/or remote sensing information. Earthquake moment tensor contains relatively complete focal mechanism information. In this study, 21 events utilized using broadband seismic waveforms. With magnitudes ≥ 3.5, for which focal mechanism solutions for these earthquakes had been determined. Most of the events are located inside the northern Iraq, some of them on or near to the borders with Iran and/or Turkey. Seismologists refer to the direction of slip in an earthquake and the orientation of the fault on which it occurs as the focal mechanism. Different types of focal mechanisms can be defined by beach-ball diagram.

FMS had been done because the pattern of radiated seismic waves depends on the fault geometry. This method attempts to find the best fit to the waveforms (T-R-Z rotated three-component seismogram) observed at each station. One of the processed broadband seismic waveforms had been taken from Kandilli Observatory and Earthquake Research Institute (KOERI) for which the focal mechanism was determined. The event occurred in Aug, 2013, 2013/08/02 at 01:10:27.0.

Earthquake data

Table1 shows 21 events occurred in the study area that were selected in the time period from 2013 to 2017. Focal mechanism solutions is possible to be estimated by a parameters of earthquakes derived from different catalogs, such as Sulaimani and Duhok University Observatories, Kandilli Observatory and Earthquake Research Institute (KOERI), Iranian Seismological Center (IRSC) and the European-Mediterranean Seismological Centre (EMSC).

Table 1. Source parameters of the 21 events taken from different sources.

Events	*Date*	*Time (UTC)*	*Lat.°*	*Long.°*	*Mw*	*Source*
July, 2013	*2013/07/13*	*17:31:47.0*	*37.05*	*45.46*	*4.1*	*KOERI*
Aug,2013	*2013/08/02*	*01:10:27.0*	*36.59*	*43.29*	*4.5*	*KOERI*
Nov,2013	*2013/11/23*	*23:26:20.0*	*34.72*	*45.38*	*5.3*	*KOERI*
Jan, 2014	*2014/01/25*	*01:48:49.0*	*36.57*	*42.30*	*3.8*	*KOERI*
Dec ,2015	*2015/12/09*	*22:33:09.9*	*35.30*	*44.88*	*3.8*	*SUO*
Dec ,2015	*2015/12/09*	*22:08:59.9*	*35.42*	*44.21*	*3.5*	*SUO*
Dec ,2015	*2015/12/10*	*00:41:25.8*	*35.31*	*44.77*	*4.1*	*DHK*
Dec, 2015	*2015/12/10*	*02:18:28.0*	*35.33*	*44.91*	*3.5*	*SUO*
Dec ,2015	*2015/12/10*	*09:51:13.0*	*35.27*	*44.73*	*3.6*	*SUO*
Dec ,2015	*2015/12/10*	*00:41:25.8*	*35.31*	*44.77*	*4.1*	*SUO*
Dec ,2015	*2015/12/10*	*00:39:34.6*	*35.21*	*44.64*	*3.9*	*SUO*
Apr ,2016	*2016/04/17*	*03:22:39.1*	*35.88*	*45.27*	*3.8*	*SUO*
Jun, 2016	*2016/6/11*	*10:00:00.0*	*33.66*	*46.1*	*3.9*	*SUO*
Dec ,2016	*2016/12/24*	*12:00:21.3*	*36.71*	*43.0*	*3.8*	*SUO*
Dec ,2016	*2016/12/24*	*12:00:21.3*	*36.71*	*43.0*	*3.8*	*DHK*
Feb ,2017	*2017/02/15*	*22:28:14.0*	*37.32*	*44.69*	*3.8*	*SUO*
Feb ,2017	*2017/02/17*	*23:00:00*	*36.31*	*41.24*	*4.1*	*SUO*
Feb ,2017	*2017/02/17*	*23:00:59.2*	*36.31*	*41.29*	*4.1*	*DHK*
Feb ,2017	*2017/02/17*	*23:00:59.2*	*36.31*	*41.29*	*4.1*	*SUO*
Feb ,2017	*2017/02/19*	*19:19:23.4*	*37.51*	*42.68*	*3.5*	*SUO*
Feb ,2017	*2017/02/20*	*15:47:19.3*	*36.47*	*45.30*	*3.6*	*SUO*

The location of this event with lat. =36.59° and long. =43.29° and the stations used for the waveform inversion are shown in the *(Figure:2)*. The Magnitude of this selected event is Mw=4.5.

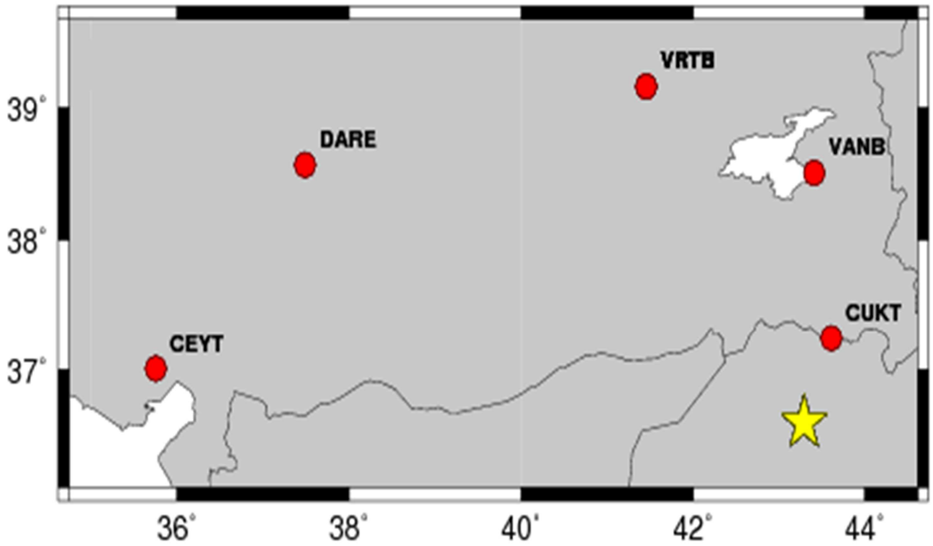

Figure-2: Location of broadband stations (red colors) used for waveform inversion. The star represent the event location.

The software wvfgrd96 turned into used determine the focal mechanism, depth and seismic moment. This approach requires a high first-rate signal and properly decided the models of velocity for the Green functions. The calculated and predicted traces are filtered using gsac commands. The satisfactory solution and the result of the grid search from 0.5 to 39 km depth is as follows:

Depth= 28.0Km, Strike= 190°, Dip=90°, Rake=75 and Magnitude=5.14. The best fit as a function of depth and the mechanism corresponding to the best fit is shown in the *(Figure: 3A and 3B)* respectively.

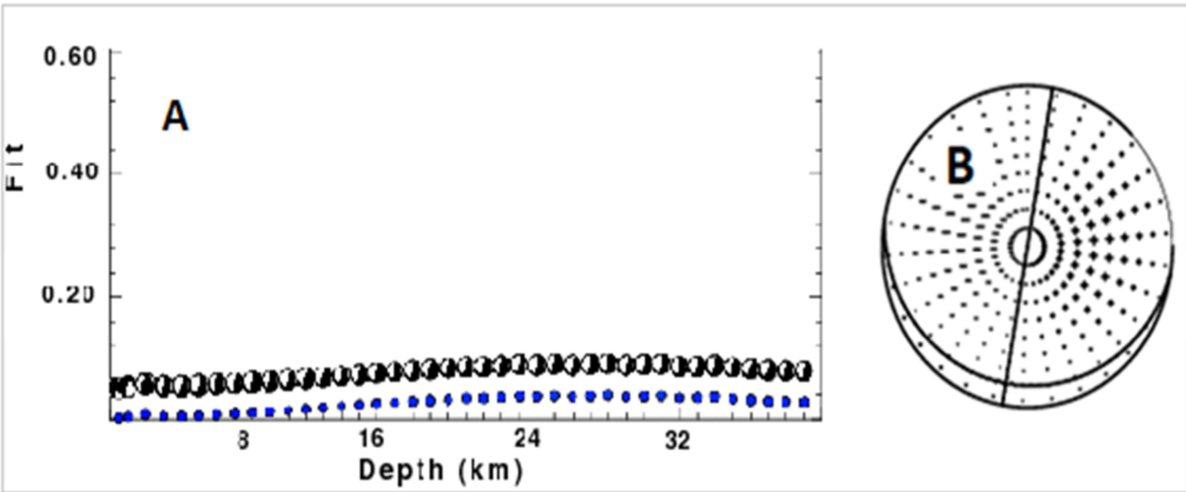

Figure-3: A- Shows depth sensitivity for waveform mechanism and B- Waveform inversion focal mechanism.

The bandpass filter employed in the processing and for observed and anticipated waveform is proven in figure4. The red traces are the observed and the blue are the predicted. Each observed-anticipated section is plotted to the equal scale and height amplitudes are indicated via the numbers to the left of each trace. A couple of numbers is given in black at the right of each predicted traces.

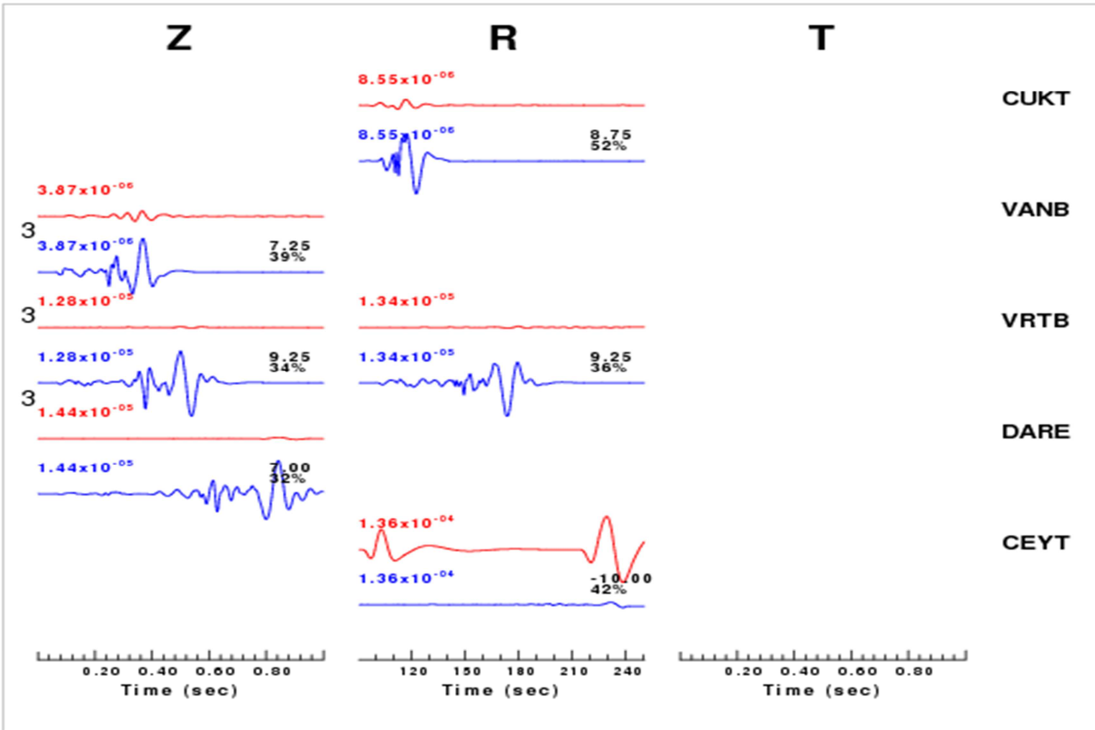

Figure- 4: The observed and predicted waveforms.

The comparison between the calculated focal mechanisms for an event occurred at Lat. (35.31°) and Long. (44.77°) in Dec, 2015 (2015/12/10) at the time (00:41:25.8) recorded by two different seismic stations, Sulaimani and Duhok University Observatories (SUO) and (DHK) simultaneously is shown in the next figures. The location of the event and stations used for the waveform inversion with the waveform inversion focal mechanism are displayed in the (*Figure: 5).*

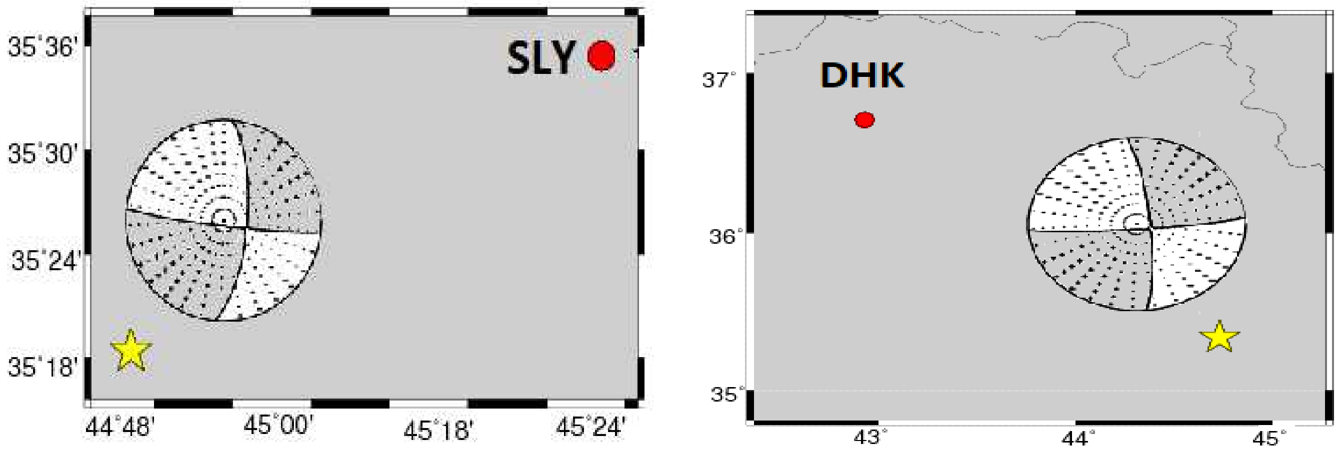

Figure-5: Location of broadband stations (red colors) used for waveform inversion. The star represent the event location.

The computed best solution recorded by SUO is:

(Depth, Strike, Dip and Rake which is the direction a hanging wall block moves during rupture) were (17.0, 5, 70 and -5) respectively and the measured Magnitude (Mw) is 4.1. While The measured best solution results recorded by DHK is: (Depth, Strike, Dip and Rake were (23Km ,355, 80 and -5) respectively from 0.5 to 39 km depth and the moment Magnitude (Mw) is 4.1.

The best fit as a function of depth is given in the following *(Figure: 6):*

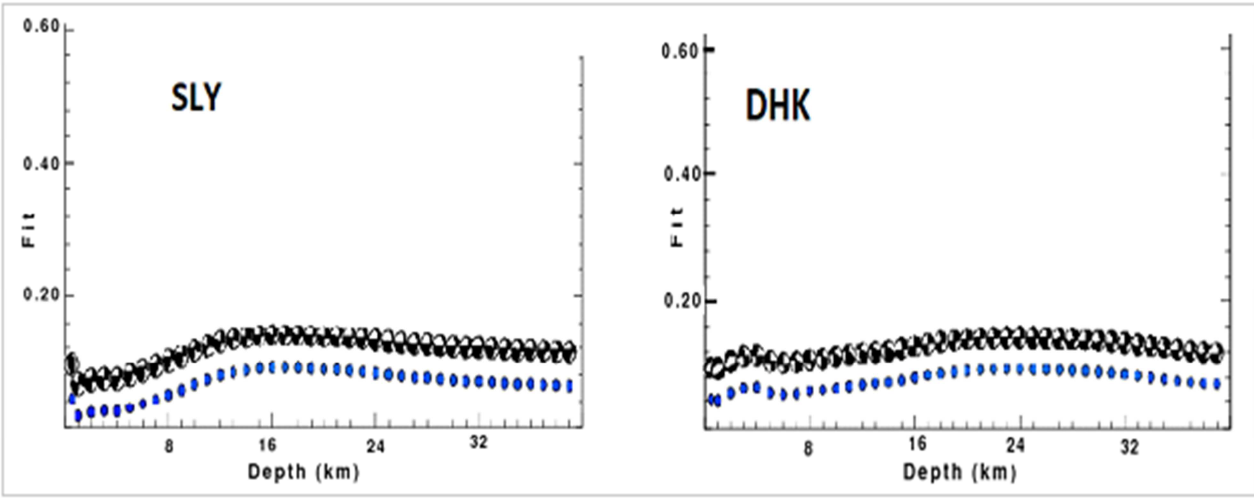

Figure -6: Shows depth sensitivity for waveform mechanism.

The assessment of the observed and predicted waveforms by two different seismic stations is given in the (*Figure:7)*. The upper number is the time shift required for maximum correlation between the observed and predicted traces. In the processing a bandpass filter was used with a suitable velocity model in the predictions.

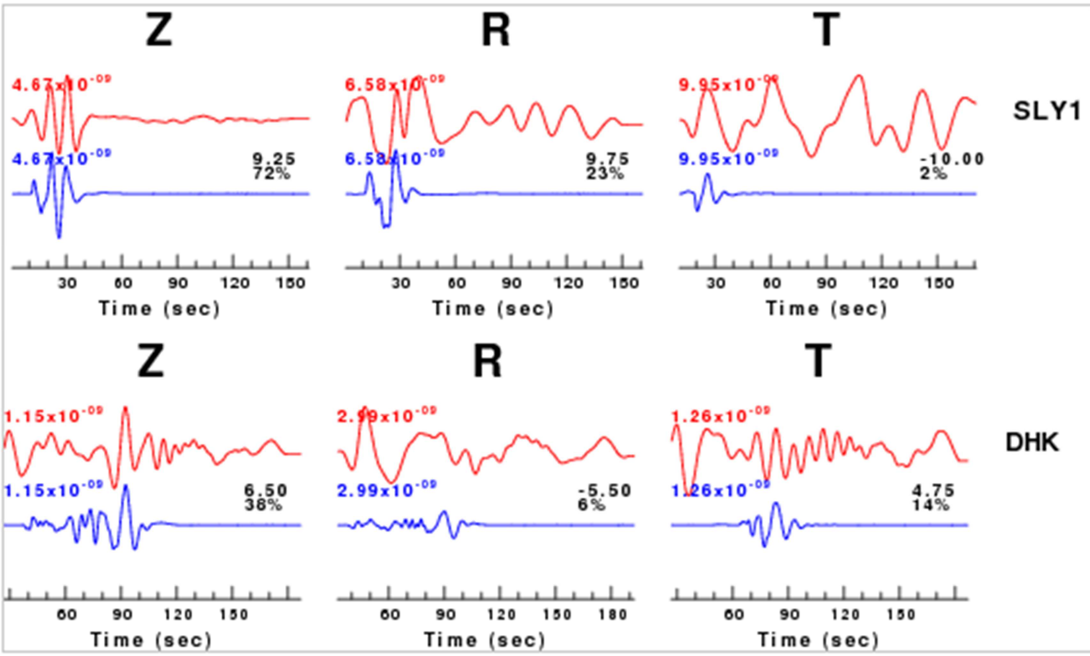

Figure-7: Shows the observed and predicted waveforms for the event occurred at Lat. (35.31°) and Long. (44.77°) in Dec, 2015 by two different seismic stations.

Results

In the following table 2, Focal Mechanism Solutions are shown for 21 earthquakes in the study area which recorded by KOERI, SUO and DHK stations. The calculated depth of the events between 10-39 km. The value of the moment magnitude ranges from (3.5) to (5.3). The measured dip = 90° and rake = 0° for the event as occurred in Jan, 2014 at (01:48:49.0) and recorded by KOERI catalog depict strike-slip fault. But, the event occurred in Aug, 2013 with moment magnitude 4.5 recorded at (KOERI) in (2013/08/02) at (01:10:27.0) with strike and rake equal to (190°), (75°) respectively indicate vertical fault. A rake of 0° means the hanging wall, or the right side of a vertical fault, moved away from the observer in the strike direction. Furthermore, the occurred event with (Mw= 4.1) in Dec, 2015 (2015/12/10) at(00:41:25.8) with strike (355°,5), high dip angle(80°,70°) and rake angle equal to(5°,5°) recorded at DHK and SUO stations respectively indicate strike slip fault.

Table-2: FMS of 21 earthquakes recorded by KOERI catalog, (SUO and DHK) stations.

Events	*Date*	*Time(UT)*	*Depth (Km)*	*Strike °*	*Dip °*	*Rake angle°*	*Mw*	*Source*
July, 2013	*2013/07/13*	*17:31:47.0*	*20.0*	*30*	*70*	*45*	*4.1*	*KOERI*
Aug,2013	*2013/08/02*	*01:10:27.0*	*28.0*	*190*	*90*	*75*	*4.5*	*KOERI*
Nov,2013	*2013/11/23*	*23:26:20.0*	*10*	*330*	*35*	*80*	*5.3*	*KOERI*
Jan, 2014	*2014/01/25*	*01:48:49.0*	*19*	*5*	*90*	*0*	*3.8*	*KOERI*
Dec ,2015	*2015/12/09*	*22:33:09.9*	*36.0*	*215*	*80*	*85*	*3.8*	*SUO*
Dec ,2015	*2015/12/09*	*22:08:59.9*	*17.0*	*150*	*25*	*20*	*3.5*	*SUO*
Dec ,2015	*2015/12/10*	*00:41:25.8*	*23.0*	*355*	*80*	*5*	*4.1*	*DHK*
Dec, 2015	*2015/12/10*	*02:18:28.0*	*19.0*	*170*	*0*	*25*	*3.5*	*SUO*
Dec ,2015	*2015/12/10*	*09:51:13.0*	*38.0*	*20*	*85*	*55*	*3.6*	*SUO*
Dec ,2015	*2015/12/10*	*00:41:25.8*	*17.0*	*5*	*70*	*5*	*4.1*	*SUO*
Dec ,2015	*2015/12/10*	*00:39:34.6*	*16.0*	*190*	*60*	*35*	*3.9*	*SUO*
Apr ,2016	*2016/04/17*	*03:22:39.1*	*37.0*	*210*	*50*	*30*	*3.8*	*SUO*
Jun,2016	*2016/06/11*	*10:00:00.0*	*38.0*	*10*	*90*	*75*	*3.9*	*SUO*
Dec ,2016	*2016/12/24*	*12:00:21.3*	*39.0*	*260*	*80*	*40*	*3.8*	*SUO*
Dec ,2016	*2016/12/24*	*12:00:21.3*	*39.0*	*90*	*15*	*50*	*3.8*	*DHK*
Feb ,2017	*2017/02/15*	*22:28:14.0*	*23.0*	*325*	*85*	*70*	*3.8*	*SUO*
Feb ,2017	*2017/02/17*	*23:00:59.2*	*39.0*	*270*	*75*	*45*	*4.1*	*DHK*
Feb ,2017	*2017/02/17*	*23:00:00*	*39.0*	*300*	*70*	*70*	*4.1*	*SUO*
Dec ,2017	*2017/02/17*	*23:00:59.2*	*39.0*	*50*	*70*	*5*	*4.1*	*SUO*
Feb ,2017	*2017/02/19*	*19:19:23.4*	*39.0*	*350*	*80*	*15*	*3.5*	*SUO*
Feb ,2017	*2017/02/20*	*15:47:19.3*	*35.0*	*5*	*90*	*85*	*3.6*	*SUO*

Conclusions

The results of this study, together with investigations of other earthquakes, suggest that the used broadband networks can be used efficiently for determining source parameters of earthquakes of magnitude greater than 3.5 in regions with moderate seismicity. In general, the waveform inversion results for most of the events indicate that the responsible fault were mostly a strike-slip fault, although some dip-slip faults were estimated. In comparison between the computed focal mechanisms for the same event for example the event that occurred in (2015-12-10) and recorded by both stations; Sulaimani and Duhok University Observatories (SUO) and (DHK) respectively, the fit is not equally well. FMS resulted from SUO records gave more waveform matching percentage because this event occurred nearer to SUO than to DHK respectively, the fit is not equally well. The time differences between the observed and predicted traces is possible which arise in the processing of waveform matching for the assumed source location. The NE dipping thrust faults, foreland verging over thrust anticlines are the most dominant structures in this Zone. Numan [7] considers this zone part of the Foreland Basin which is subdivided into; High Folded Zone and Imbricate Zone.

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