Moment Tensor Inversion of Some Events of Qeshm Island Earthquake Sequences Using INSN Broadband Data

Alireza Alinaghi

Seismology Research Center, International Institute for Earthquake Engineering and Seismology, IIEES, I.R. Iran, email: alinaghi@iiees.ac.ir

ABSTRACT: *Regional moment tensor inversion of the mainshock and three aftershocks of earthquake series in and around Qeshm island in the Persian Gulf has been carried out using high quality broadband data from Iran National Seismic Network (INSN). The events which have been recorded at regional distances by stations of INSN have started to jolt the island and the mainland Iran in two sequences starting in November 2005 with a Mw=5.9 event and yet with another series of events in June 2006 with a Mw=5.8 earthquake. The results of the analysis for the main shock and three aftershocks from the two above mentioned earthquake series are presented. From the focal mechanism solutions, it appears that a mainly south-north trending compressional axis prevails. Apart from a major aftershock in the first earthquake series which shows the strike-slip mechanism with small normal component of slip, the main shock and the other two aftershocks show large component of reverse faulting along causative faults trending NEE-SWW to SE-NW. The horizontal components of main compressional axes deduced from obtained solutions suggest south-north directions which are in accordance with the expected axes of shortening.*

Keywords: INSN broadband data; Moment tensor; Inversion; Earthquake sequences

1. Introduction

The Qeshm island is situated in the Persian Gulf about 20*km* south of the port city of Bandar-Abbas. Geologically speaking, the island is part of the Zagros fold belt, which stands clear of water and is made of marly sediments. There are three major anticlines in the island, trending *SW-NE*, *NW-SE* and *NE-SW*. There have been no documented active faults in the island prior to the earthquake series which have been investigated in this article. The general trends of folds north of the Qeshm island in the mainland Iran, being part of the Zagros system, from northwest to southeast, are mainly northeast-southwest, east-west, northeast-southwest which suggest a change in the trend of structures from west and central Zagros towards southeast Zagros where seismicity and mountain ranges disappear into Makran region. It is assumed that the rotation of axes of compression during consecutive geological epochs has led to the formation of such diverse foldings.

The Qeshm island marks the southern edge of the Zagros fold system where seismicity of Zagros diffuses into the Persian Gulf. Based on historical records a few destructive earthquakes have inflicted damages on the island in the past centuries. The relocation of events of the twentieth century and beyond shows that the island has been the locale of only a few background events, see Figure (1). Nevertheless, in November 2005 with a Mw = 5.9 earthquake, the relative seismic quiescence of the island ended and a number of moderate and small earthquakes jolted the island that were also felt in the mainland Iran, see Figure (2). The earthquakes which inflicted damages to adobe buildings raised concerns about seismic activity of an area formerly considered quiet and safe.

The purpose of this study is to test the efficiency

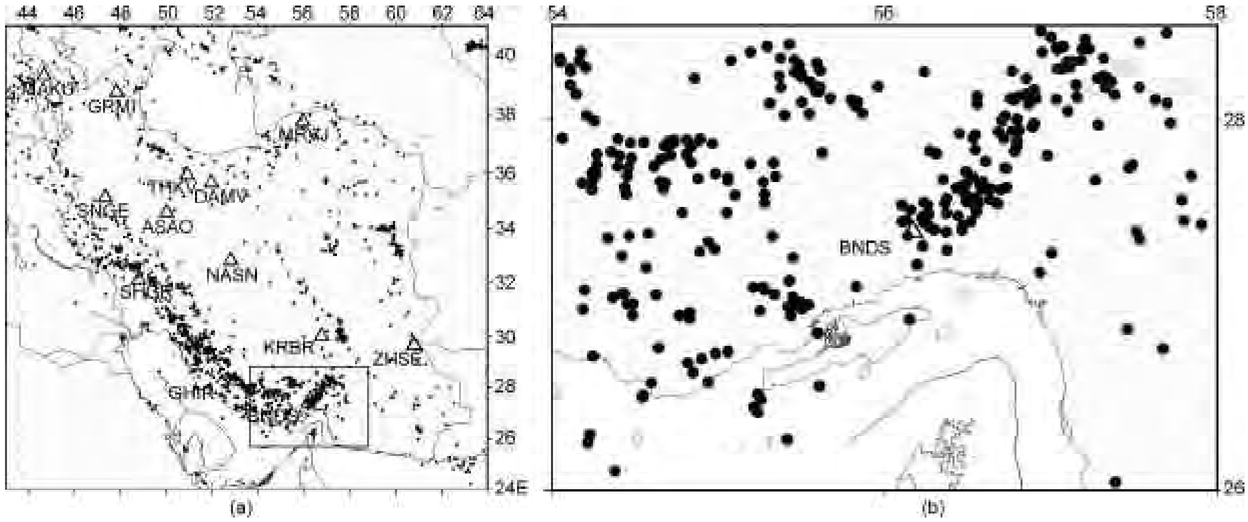

Figure 1. a) Seismicity of Iran from 1900 to the end of 2004 (based on data from [3]) and distribution of INSN broadband stations (hollow triangles) with station abbreviations. The study area has been marked on the map. b) The study area as part of the southeast Zagros and the Qeshm island with seismicity are shown as filled circles.

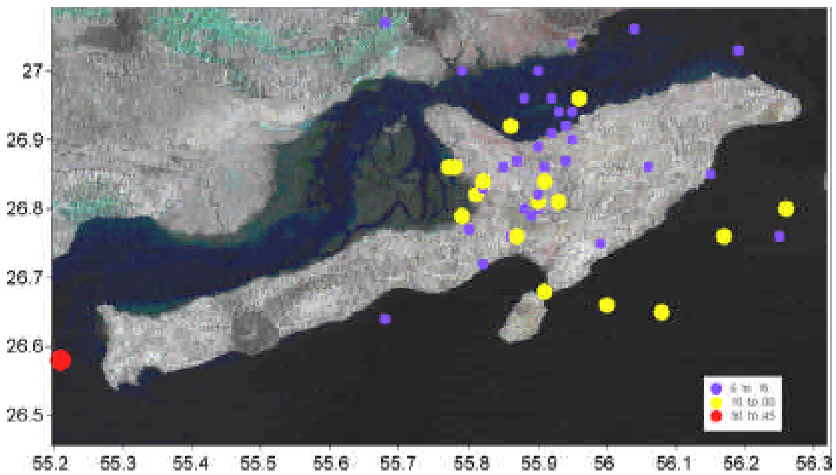

Figure 2. The location of the earthquakes occurred on the island and around it during November 2005 through October 2006, as determined by IIEES, plotted on a satellite photo, showing the Qeshm island and edge of the mainland Iran. The annotations of horizontal and vertical axes represent geographical longitudes and latitudes, respectively.

of the applied method on data from a sparse network of stations and tune it with respect to the quality of our data for a full scale upcoming study. Besides, the author would like to find out more about the nature of earthquakes occurring on the edge of the Iranian plateau and find out whether these earthquakes can help in delineating the boundary of the Arabian shield and Iran microplate.

2. Data

Broadband recordings from stations of Iran National Seismic Network (*INSN*), as shown by *IIEES* in the epicentral distance range of about 50 to 600*km* have been used. The stations are equipped with Guralp *CMG*-3T 100*sec* broadband seismometers and 24 bit Guralp data loggers. The broadband nature of recordings has enabled the author to filter the data in the frequency range of 0.01-0.03*Hz*, suitable for regional moment tensor inversion.

3. Methodology

Full waveform three component time domain inversion method [2] was applied to the data for obtaining components of seismic moment tensors. This method enables the author to use data from a sparse network of broadband stations and perform the inversion successfully. For calculation of Green's functions, a 1*D* velocity model has been used to approximate the velocity structure of the crust. The model has the crust-mantle boundary set at the depth of 40*km*, i.e. the average value, considered based on receiver function studies [e.g. 1], see Table (1). Prior to inversion, both synthetic and observed seismograms are band passed between 0.01 and 0.03*Hz* to avoid high frequency complexities in the crustal structure.

Table 1. The velocity model used for calculation of Green' s functions with two crustal layers atop the half-space, with Vp, P wave velocity, Vs, S wave velocity, ρ, the density, and Qα and Qβ as attenuation coefficients for P and S waves, respectively.

Thickness (km)	Vp	Vs	?	Qa	Qß
15	5.8	5.8	5.8	225	100
25	6.8	3.9	2.9	225	100
600	8.1	4.5	3.3	225	100

4. Results

The results of applying this method to the mainshock and three aftershocks are presented here. For comparison purposes, the available results from Harvard University moment tensor inversion are also presented, which cover two of the events analyzed here, see Figure (3).

In Figure (4), the result of the inversion for the main shock is presented. The data from Ghir (*GHIR*) and Zahedan (*ZHSF*) and Kerman (*KRBR*) stations at epicentral distances of 320*km*, 560*km*, and 370*km*, have been used, respectively. The reverse faulting mechanism is in agreement with most mechanisms observed in Zagros system. The good fit of the synthetics with the observed is an indication of high quality solution even though only three stations have been used in the analysis. The compressional axis calculated is trending *SSW-NNE* and is in accordance with the expectation based on the tectonic settings of the area.

In order to estimate the depth of the hypocenter of the main shock, calculations were done using Green's functions for depths of 7, 10, 13, and 17*km*. The results of inversion shown in Figure (5) are in good agreement with one another in terms of the orientations of the fault planes. The result for the depth of 7*km* gives the highest amount of variance reduction among solutions. Therefore, the depth of 7*km* was chosen as the centroid depth.

Figures (6) and (7) reflect the results of the inversion for two aftershocks; one from the first series in November 2005 (*Mw* = 5.6) and the other (*Mw* = 4.1) from the second series of events starting in June 2006. It is clear that like the main shock, a large component of reverse faulting is involved with rotation of the compressional axis towards west and introduction of strike-slip component of slip. And, finally Figure (8) shows the solution that was obtained for a major aftershock in the same day as the mainshock but with striking difference from the main event. Unlike the mainshock and two aftershocks discussed earlier, there is a dominant component of strike-slip with normal faulting.

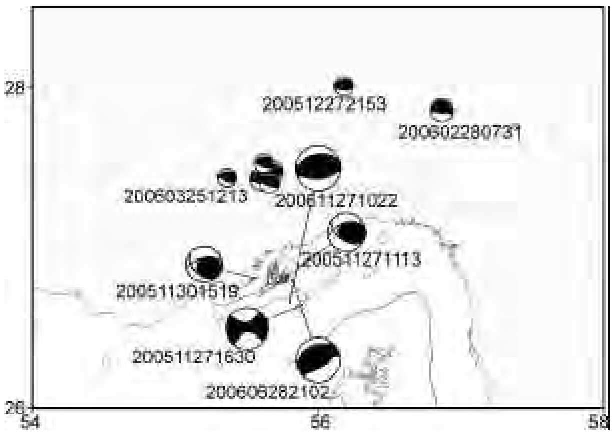

Figure 3. Focal mechanism solutions of the main shock and some major aftershocks as determined by Harvard university. The numbers underneath the beach balls represent the origin time of the events. Mechanisms of some of the earthquakes in the mainland Iran during the period of observation have also been shown on the map as smaller beach balls.

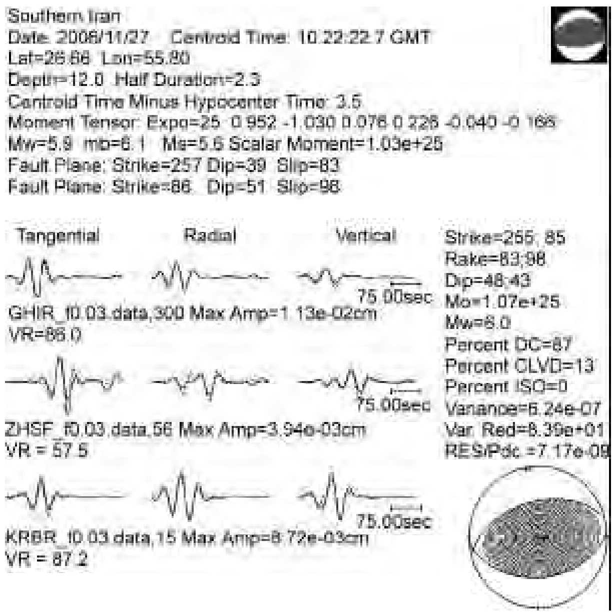

Figure 4. The result of data inversion from GHIR (distance of 320km) and ZHSF (distance of 560km) stations for the main shock of Qeshm earthquakes with waveform fit (bottom of the figure) as compared with Harvard University results (top of the figure). The data are shown as solid lines and the synthetics are dashed.

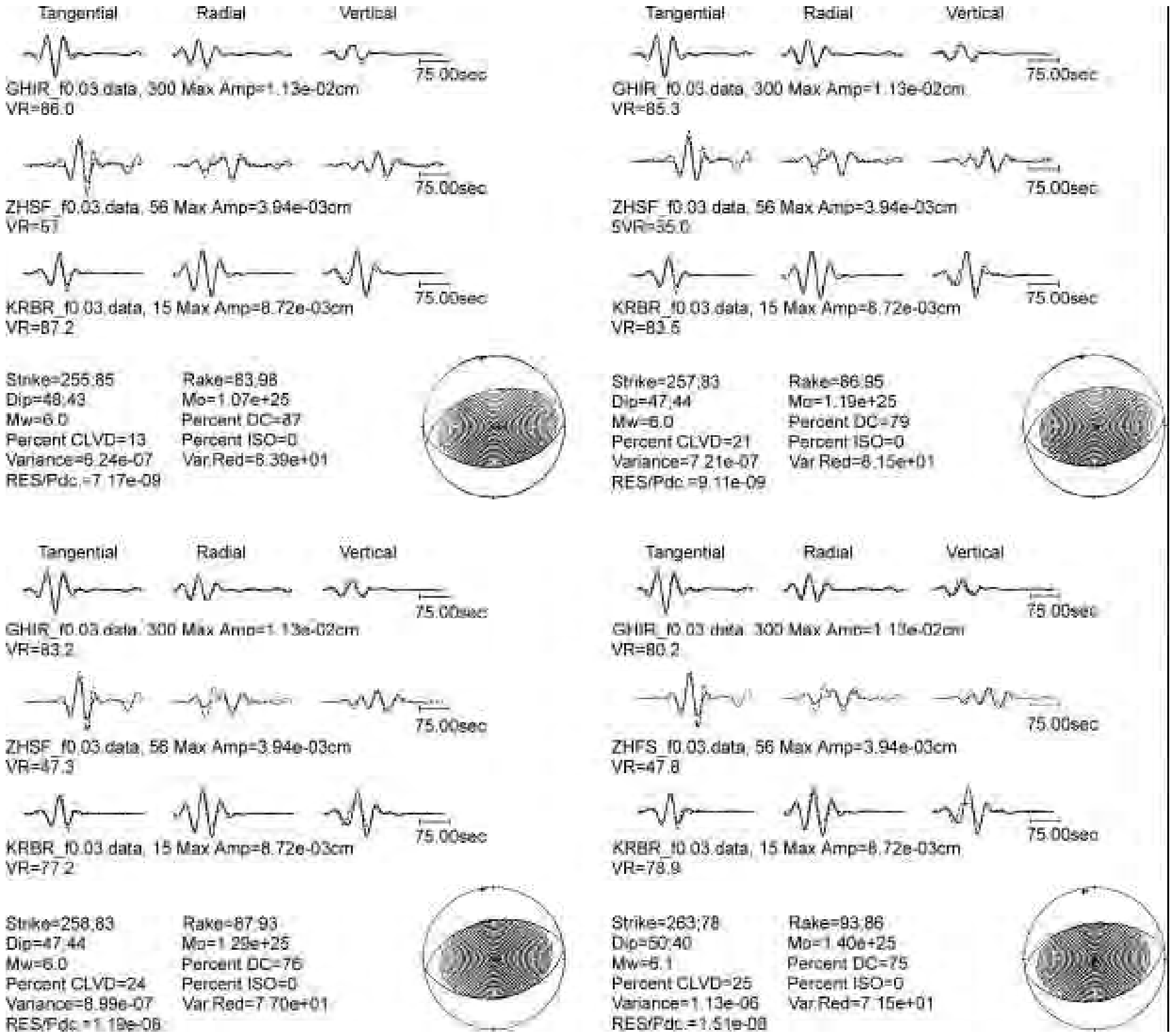

Figure 5. The results of inversion for 4 different depths: 7km (top left), 10km (top right), 13km (bottom left), and 17km (bottom right). The amount of variance reduction indicated in each panel is the highest for the depth of 7km. The data are shown as solid lines and the synthetics are dashed.

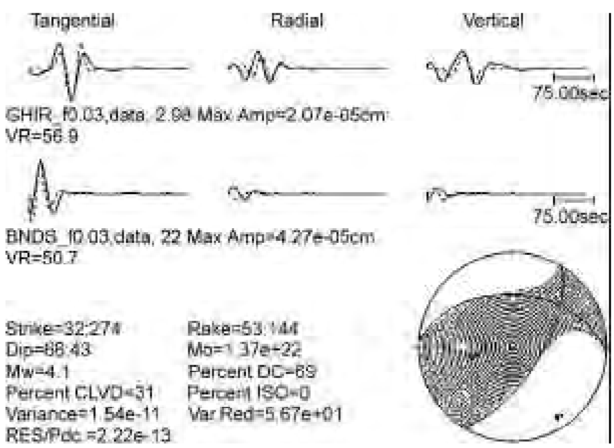

Figure 6. The result of modeling a minor aftershock with ML = 4.1 as located by IIEES which have occurred on 06.06.03 at 07:14 origin time. Full waveform three components of BNDS (distance of 66km) and GHIR (distance of 320km) stations have been inverted and waveform fit is depicted. The data are shown as solid lines and the synthetics are dashed.

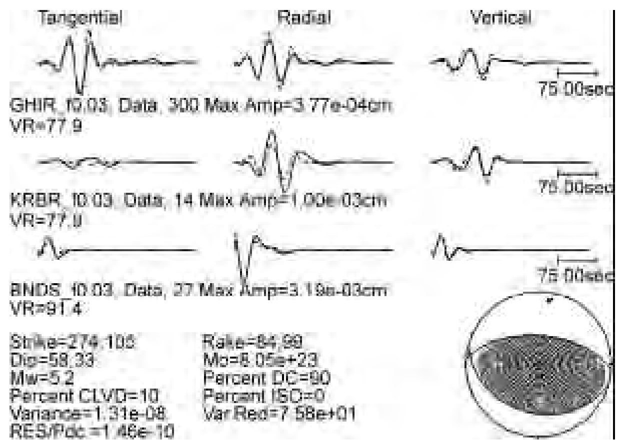

Figure 7. The result of inversion of a major aftershock (Mw = 5.3) occurred on 03.06.05 at 07:15 origin time and was located by IIEES at lat: 26.87 and lon: 55.87 in Qeshm island using data from GHIR (distance of 320km), KRBR (distance of 370km) and BNDS (distance of65km) stations. The data are shown as solid lines and the synthetics are dashed.

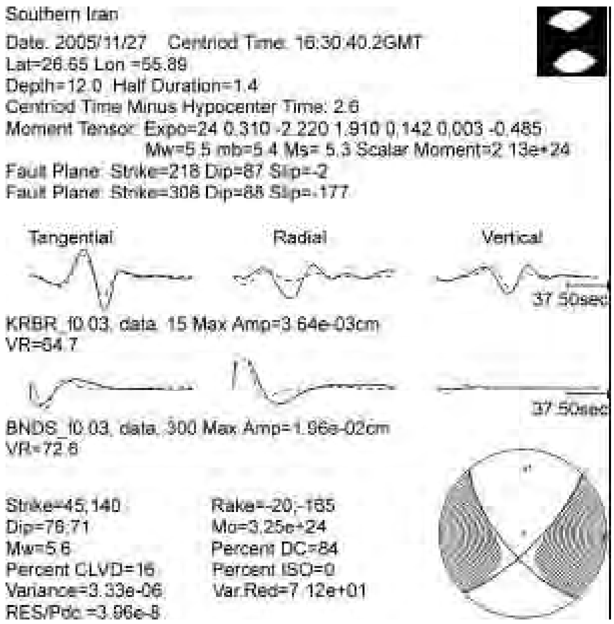

Figure 8. The result of modeling a major aftershock occurred only hours after the main shock using data from KRBR (distance of 360km) and BNDS (distance of 72km) stations with waveform at the bottom of the figure. At the top of the figure, the result of inversion from Harvard university with the corresponding beach-ball representation is shown. The data are shown as solid lines and the synthetics are dashed.

5. Conclusions

It has been shown that applying the time domain moment tensor inversion method to data of a sparse broadband network of seismic stations, can yield satisfactory solutions of earthquake mechanism. Since our knowledge of velocity structure in the region is inadequate, the frequency band of observation have been limited to long period signals.

The existence of Harvard University solutions for the two earthquakes are studied here and the satisfactory agreement between them and obtained results have proved the efficiency of our method further.

The mechanism of the main event with large component of reverse faulting is what was expected based on our knowledge of tectonic setting in the area. This has also been observed in two other aftershocks analyzed even though varying amounts of strike-slip component of slip are also involved. Based on the geometry of observing stations in which all are located in the north of events, there is still doubt about the errors involved with calculated strike of nodal planes as well as the amount and sense of strike slip movements.

The depth of the main shock as inferred from inversions for various depths was shown to be 7*km* which is quite common for shallow earthquakes in Zagros.

One studied aftershock ($Mw = 5.6$) which occurred a few hours after the main shock, shows strikingly different mechanism than the main shock with a large component of strike slip and small amount of normal faulting. It seems that the stress field which has caused the main event has activated other fault systems with different mechanism. In spite of the change of apparent mechanism, the horizontal comprssional axis is trending from *SSW-NNE* to *SSE-NNW* in accordance with the regional stress field predicted by global models of plate motions as well as ground *GPS* studies.

The occurrence of above mentioned series of events in an island formerly quiet and almost aseismic, shows the migration of clustered seismicity of Zagros to the south and that the Qeshm island marks the active boundary between the Arabian shield and Iranian microplate.

References

1. Alinaghi, A., Kind, R., and Sodoudi, F. (2002). “Receiver Function Probing of the Crust in Northern Iran”, Abstract, AGU Fall Meeting, San Francisco, USA.

2. Dreger, D.S. (2003). “TDMT_INV: Time Domain Seismic Moment Tensor Inversion”, International Handbook of Earthquake and Engineering Seismology, **81B**, 1627p.

3. Engdahl, E.R., Van Der Hilst, R., and Buland, R. (1998). “Global Teleseismic Earthquake Relocation with Improved Travel Times and Procedures for Depth Determination”, Bull. Seism. Soc. Am., **88**, 722-743.