ویژگیهای زمین لرزه ویرانگر هشتم خرداد ماه ۸۳ بلده- کجور در البرز مرکزی با تحلیل شکل موج میدان دور

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Source Characteristics of the 28th May2004 Baladeh-Kojour Destructive Earthquake in Central Alborz, Revealed from far Field Waveform Data

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چکیده

در این مقاله، ویژگیهای چشمه زمین لرزه ویرانگر هشتم خرداد ماه ۸۳ بلده- کجور به روش برگردان شکل موج ثبت شده در میدان دور بررسی می شود. از مشاهدات صحرایی و فعالیت پس لرزه ها به عنوان اطلاعات تکمیلی برای تعیین پارامترهای چشمه استفاده شده است. چشمه زمین لرزه اصلی دست کم به‌صورت سه زیر رویداد مدل شده است. شکستگی با رویداد اول در محل کانونی شروع و به طور عمده یک طرفه به سمت باختر گسترش یافته است. جا به جایی اصلی، در ۱۰ ثانیه اول رخ داده است و جهت یافتگی، عمده‌ترین عامل برای گسترش شدت در ناحیه کانونی است. سازوکار به دست آمده عمدتا رورانده بوده و با سازوکار دیگر زمین لرزه ها و عملکرد نیروهای زمین ساختی در این منطقه همخوانی دارد. گشتاور لرزه ای حدود $۴/۱\times ۱۰^{۱۸}$ نیوتن متر و بزرگی گشتاوری ۶/۳ محاسبه شده است. مدت دوام بزرگ‌ترین رویداد حدود ۷ ثانیه و طول شکستگی ۲۰ کیلومتر تعیین شده و بیشترین جابجایی حدود ۱۲۰ سانتیمتر و افت تنش ۲۵ بار برآورد شده است. توزیع حرکت نیرومند زمین، دو ناحیه با شتاب زیاد را نشان می‌دهد. بدین ترتیب، یا چشمه مسبب چند رویدادی بوده و یا محیط باعث تشدید حرکت شده است. این ابهام را می‌توان با مطالعات صحرایی رفع کرد. شواهد و شتابنگاشتهای ثبت شده در ناحیه بلده نشان می دهد که حرکت نیرومند زمین به هنگام زمین لرزه اصلی شدید بوده است. گرچه البرز مرکزی از لحاظ تاریخی لرزه خیز بوده ، اما زمین لرزه ای با قدرت زمین لرزه اخیر در حوالی بلده، در صد سال گذشته رخ نداده است. از لحاظ مهندسی، باید از ویژگیهای حرکت زمین لرزه بلده- کجور برای طراحی سازه های مقاوم در ناحیه آسیب دیده بهره جست.

کلیدواژه‌ها: زمین لرزه بلده- کجور، لرزه خیزی البرز مرکزی،پارامترهای چشمه، مدل سازی شکل موج، سازوکار کانونی، لرزه زمین‌ساخت، گسلهای فعال.

Abstract

Source characteristics of the 2004 Baladeh-Kojur destructive earthquake is obtained by inverting far field waveform data. The information from field investigation and aftershock activity are considered as supplementary data to constrain the source parameters. The source characteristics of main shock is explained in terms of at least three major subevents. Rupture initiated in epicentral area with the first subevent and mainly extended toward west in a unilateral manner. The major slip took place during the first 10 seconds and it is concluded that the directivity played main role for producing extensive intensity in the epicentral region. The source mechanism obtained in this study is predominantly thrust and is in agreement with the mechanism of other earthquakes as well as the orientation of tectonic forces in this region. The total seismic moment is calculated to be $M_0 = 4.1\times10^{18}$ Nm and the total moment magnitude is Mw = 6.3. The source duration of largest subevent is about 7 seconds and its related rupture extension is about 20 km. The calculated maximum dislocation is about 120 cm and the estimated maximum stress drop is about 25 bar. The distribution of strong ground motion indicates two high acceleration areas in epicentral area and toward the west. This indicates that the main shock possibly has a multiple source nature or the media has amplified the ground motion in western part of the epicentral region. This fact should be clarified by more detailed field studies in future. Macroseismic evidence and recorded accelerograms in Baladeh region indicate that the ground strong motion was intense during the main shock. Although Central Alborz had been seismicly active in historical times, there was no evidence that earthquakes as severe as this one had occurred in the vicinity of Baladeh-Kojour region during at least the past 100 years. From the engineering point of view, Baladeh-Kojour earthquake provided ground-motion characteristics of a strong event in the affected area and should be considered as the controlling event for the design of structures with high safety requirements.

Keywords: Baladeh-Kojur earthquake, Seismicity of Central Alborz, Source parameters, Waveform modeling, Focal mechanism, Seismotectonics, Active faults.

1.Introduction

On 28th May 2004 at 12h 38m 42.0s GMT, 05h 8m 42.0s p.m. in local time, a moderate but relatively destructive earthquake occurred in Baladeh-Kojour area at a distance of about 70 km in northern Tehran. The epicenter of earthquake was computed as 36.27N-51.57 E by USGS. The magnitude of main shock given by USGS, was mb=6.0 and Ms=6.3. The focal depth determination indicated a depth of 26 kilometers. According to official reports, at least 35 people were killed and 400 others were injured in this earthquake. It destroyed 2000 homes and left 10,000 homeless in the epicentral area. Many buildings were damaged in the Mazandaran-Qazvin Provinces. Some of the deaths were due to landslides and rockfalls on the Tehran-Chalus road. Infrastructures were damaged in the epicentral area. The main shock was felt in much of north central Iran. The earthquake also shook Tehran and created horror and anxiety among the population which has reached to the border of 12 million now. They rushed out of their houses and gathered in public parks and outdoors expecting more severe tremors. Fortunately, there was no official report for casualties though breaking of some window panes were reported from the western side of the city (i.e. Shahrak-e Gharb) where tremors were felt more than the other parts. Minor damages were also reported in some parts of Tehran. The time of the incident being late afternoon, at 05h 8m 42.0s p.m. on Friday, was a reason for anxious people to spend the night outdoors. The typical prediction of a catastrophic and very destructive earthquake that would follow the previous tremors in a short time, moved around the city and created more anxiety. Such predictions even moved among some experts in the field. Therefore, Tehran, if not officially but practically remained in scarlet alert for several days. Some people left their houses and even erected some tents, as shelters for the nights.

This paper uses the result of field reports and aftershock activity and studies the source characteristics of main shock by the inversion of far-field data collected by the Data Management Center of the Incorporated Research Institutions for Seismology (IRIS-DMC). The main goal is to obtain how far the rupture extended coseismically and how the directivity of rupture propagation was related to the strong ground motion distribution. First the activating fault system and the background seismicity are reviewed. Then, the waveform modeling is conducted. In the last part, the observed ground strong motion is explained and discussed.

2. Geological background

Epicentral region of the Baladeh-Kojour earthquake, which is the subject of this study, is located in Mazandaran province along the Central Alborz seismic zone which consist of a broad arch of parallel anticlines and synclines forming the southern border of the vast depression Caspian Sea (Gheitanchi et. al, 2004). They face the depressed Caspian block on the north and to the south grade into the plateau of central Iran (Priestley at. al, 1993). In its western part, the range shows structural axes trending NW-SE, roughly parallel to the northern part of the Zagros seismic zone and to the structural alinements of Caucasus (Nowroozi, 1971; Annaorazov, 1983; Chandra, 1984). On the other hand, the eastern part of Alborz is characterized by structural axes trending approximately NE-SW, parallel to the Great Kavir (Doruneh) fault (Goryachev, A.V., 1983). These two different structural trends meet in the Central Alborz, which thus shows a critical position in the framework of the range and in this zone of convergence of two different alignment that the great Quaternary volcano of Damavand has been built. Geological evidences and fault plane solutions of earthquakes in Central Alborz indicate the existence of both thrust and conjugate strike-slip faulting (McKenzie, 1972; Jackson, 1992; Akasheh and Berckhemer, 1984). In the regional scale, the Arabian and Eurasian plates are converging in a north-east direction and Alborz mountains are undergoing shortening and shear motions. The oblique motion result in dominantly thrus earthquakes and in frequent strike slip earthquakes that indicate slip partitioning (Gao and Wallace, 1995; Jackson et. al, 1995).

Using the geological information and the works done by Berberian (1976) and Jackson and McKenzie (1984), a simplified tectonic map including the epicentral distribution of instrumentally recorded strong earthquakes, reported during 1925-2004 by international agencies, and the available fault plane solutions was provided in this region which is presented in Figure 1. As indicated in this figure, several major faults and anticlines and synclines almost parallel to the southern border of the vast depression of the Caspian Sea could be understood. In addition, Central Alborz includes a remarkable number of minor faults indicating a complicated pattern of deformation.

3. Seismological background

Historical earthquakes of Iranian plateau, including central

Alborz, has been studied by several investigators (Ambraseys, 1974; Ambraseys & Melville, 1982; Berberian, 1976). Though the historical earthquakes are imperfectly known, these studies suggest that Central Alborz has experienced many destructive earthquakes in historical time. A brief explanation of significant historical earthquakes is given here.

In 856, on Tuesday December 22, there was a catastrophic earthquake in Eastern Alborz and more than 200000 people were killed. In the mountaineous regions, there were extensive ground deformation. Late in 874, a locally destructive earthquake killed 2000 of the troops that had taken refuge in Gorgan. Violent shocks continued for three days. On 23 February 958, there was a catastrophic earthquake in north central Iran. It destroyed all villages in the districts of Ray and Taliqan and much of the city of Ray was totally ruined, heavy casualties were reported. Damaging aftershocks continued for forty days. On 10 December 1119, a sever earthquake in Qazvin killed many people and caused extensive damage. In May 1177, an earthquake destroyed many towns along the southern slopes of Alborz up to the region beyond Ray and many people were killed. The Ray area, eastern Buyin Zahra and the Karaj settlements were worst affected. In 1470, an earthquake occured in Gorgan and Gonbad-e Kavus was affected by this earthquake. On Sunday 15 August 1485 and just before sunset, there was a catastrophic earthquake in Gilan affecting a large area in Gilan and Mazandaran. Aftershocks continued for six weeks keeping the survivors camping out in the open. In 1498, a destructive earthquake caused the collapse of most of houses in Gorgan, killing 1000 of its inhabitants. On 20 April 1608, there was a major earthquake in southern Gilan, causing great damage over a large area. It caused large waves in the Caspian Sea and resulted in geart alarm. In 1639, a destructive earthquake is said to have killed 12000 people in Qazvin. On 3 February 1678, an earthquake in Lahijan, followed by many aftershocks, ruined many houses, mosques and bridges. In 1687, a serious earthquake in Mazandaran destroyed many villages and triggered landslides. On 16 December 1808, a destructive shock in western Mazandaran and Taliqan destroyed many villages. In Tehran the shock caused panic and the inhabitants left their houses and camped in the open. Continuing aftershocks felt in Tehran added to the panic. In 1809, a destructive earthquake occurred in Amol and caused widespread liquefaction in the river valleys and rockfalls in the mountains. In June 1815, a strong earthquake was felt in Damavand and caused a spring of cold water to dry up. In 1825, a destructive earthquake in the Haraz Valley ruined many villages, causing the death of a large number of people. In the morning of 27 March, a major earthquake in southern Mazandaran destroyed more than 70 villages. No historical earthquake was reported in Baladeh region. More details about these earthquakes are given by Ambraseys and Melville (1982).

Compared with historical background, the seismicity of Central Alborz is better understood in the present century. However, due to the lack of a seismological network operating full time with an acceptable quality, the source parameters of earthquakes include high uncertainties (Berberian, 1976; Jackson, 1980; Jackson and Fitch, 1981). Local events with magnitudes smaller than 4.5 either are not located or do not have reliable source parameters (Ambraseys, 1978; Asudeh, 1983). The teleseismical located seismicity of the Central Alborz is relatively high and characterized by moderate shocks in the magnitude range of 5 to 6 and a very small number with magnitudes equal to or slightly greater than 7 (McKenzie, 1972; Nowroozi, 1972; Priestley et. al, 1993). From 1900 till 1924, no recorded earthquake was reported for the region. However, during 1925-2004, source parameters of about 597 instrumentally recorded teleseismic earthquakes were reported in Central Alborz by international seismological agencies. The reliability of source parameters depends on the quality and the quantity of seismic stations that have recorded these earthquakes. In the early years of nineteenth century, source parameters of earthquakes were poorly determined due to the lack of seismic stations and not enough coverage in the surrounding regions (Maggi et. al, 2000). Recently, by remarkable developments in instrumentations and new techniques, the epicenteral determination of earthquakes are much more reliable. The epicenters of these earthquakes are plotted on the faults map and indicated in Figure 1. The epicentral distribution of earthquakes in this figure indicates that seismic activity both in east and northwestern parts were remarkable during 1925-2004. Only limited earthquakes occurred in the central part of the region. No major earthquake was reported in the central part including the epicenter of 2004 Balaheh-Kojur earthquake. The reported depth for all earthquakes in this region are shallow, though due to the lack of seismic stations depth determination could not be reliable.

In 1975 a seismic array, called ILPA, was installed in southwest of Tehran. The purpose of such an array was to provide data for research on seismological detection and identification probelems (Akasheh et. al, 1976). ILPA cosists of 7 three-component broadband borehole seismometers, model 36,000 in depths of about 100 m, developed by Geotech. The array is circular in shape with 6 seismometers forming the circle and the seventh located in the center of the array. The diameter of array is about 60 km. The central recording is located in the institute of Geophysics, Tehran university. More details about the specification and operation of ILPA are given by Akasheh et. al (1976). During 1975-1996 many earthquakes were recorded by ILPA. The epicentral distribution of these earthquakes is given in Figure 5. This map shows that the region is seismically active. In northwest, southwest and eastern parts, the seismic activity is significant. However, the central part indicates relatively low rate of seismic activity.

In 1996, as a part of national seismic network, the Institute of Geophysics of Tehran University deployed a telemetric seismic network in Central Alborz to monitor the seismic activity. The network includes twelve remote stations and is designed to cover the major part of Alborz where the city of Tehran with dense population is located. The epicentral distribution of the locally located earthquakes by Tehran seismic network, in Central Alborz, is indicated on the faults map in Figure 6. As it is shown in this map, the seismic activity is not uniformly distributed in the region. The major seismically active area in central Alborz, during 1996-2004, is located in northwest in the vicinity of the epicenter of the 1990 Roudbar destructive earthquake, in south and southeast around the Semnan province. The epicenters of local earthquakes are in agreement with the trends of major faults. There is a good agreement between the Figures 5 and 6. Both indicate that the central part including the epicentral region of the 2004 Baladeh-Kojur earthquake had low rate of seismic activity during 1975-2004.

4. Source characteristics of main shock

The magnitude, origin time and the hypocentral location of the main shock were given by several agencies. The USGS and Harvard University as their routine work published the source mechanism immediately after the occurrence of the main shock. Both CMT solutions indicate predominantly thrust type mechanism ,in agreement with the mechanism of other earthquakes in this region (Gheitanchi, 2004). The seismic moment calculated by USGS (M_0= 2.5×10^{18} Nm) is smaller than evaluated by HRVD (M_0= 3.3×10^{18} Nm). The source parameters obtained by USGS and the University of Harvard as well as the result of this study are given in Table 1.

Using the inversion technique developed by Kikuchi and Kanamori (1991), the long-period body waves of the Baladeh-Kojur earthquake recorded by GDSN stations were inverted to their sources to investigate the source characteristics. The waveforms of twenty-two stations with epicentral distances between 30 and 100 degrees were selected from the viewpoint of good coverage and used in the waveform inversion. The locations of selected seismic stations are given in Table 2. The data were band-passed filtered between 0.01 and 0.8 and converted into ground displacement with a sampling interval of 0.5 second. Both the observed and synthetic Green's functions were equalized for all the stations to GDSN seismograms with the same gain. In calculating the synthetic wavelet for a point dislocation the Jeffreys-Bullen A model was used (Jeffreys and Bullen, 1958). First, a source time function of trapezoid shape having rise time of 3 seconds and process time of 4 seconds was best fitted. Then, with the fixed source time function, the data was inverted for several source depths. The residual error was minimized for the depth of 10-12 kilometers. This suggested that the centroid depth was not deeper than 12 km. In next stage, by a point source approximation, we obtained the mechanism solution. Finally, for a fixed fault plane, the spatio-temporal distribution of fault slip was determined by the waveform inversion procedure, in which, the slip direction was allowed to vary. The comparison of observed and synthetic seismograms after the first iteration is given in Figure 5. This figure indicates that the fit of observed and synthetic waveforms is acceptable for the first 20 seconds. The iteration was repeated three times; no significant decrease in the residual error was found after the third iteration. This suggested that there were at least three main fault slip during the source process of the main shock. The mechanism of subevents is dominantly thrusting with a small difference in strike. The largest slip took place during the first 10 seconds and the third slip initiated after 20 seconds. Out of two possible fault planes, the one striking N130˚W gave a much better variance reduction and was in agreement with the strike of faults in the region. The mechanism solution for the total source was obtained as striking N130˚W, dipping 28˚ NE, and having rake angle of 84˚. The fault slip was consistent with the geological evidences such as folding and thrust type faulting in the region. The total seismic moment was calculated to be M_0= 4.1×10^{28} Nm. The calculated maximum dislocation was about 50 cm and the obtained moment magnitude in this analysis was Mw = 6.3, while the estimated rupture velocity was 3.0 km/s. Using the relation $\Delta\sigma = 2.5M_0/(S)^{3/2}$ and approximating the rupture area, S, by L×(L/2), where L=40 km was the fault length which was estimated by the extension of aftershock activity, thus the average stress drop, Δσ, could be estimated (Gheitanchi et al., 1993). In this study, following the same relation, the stress drop, Δσ, was estimated to be about 25 bar for the first subevent. Using the relation $M_0 = \mu DS$, where $\mu = 3 \times 10^{11}$ dyne cm^{-2} was the rigidity and S the fault area, the related dislocation, D, was calculated to be 120 cm. Examples of the observed and synthetic waveforms, the focal mechanism and the ray directions of the stations used in this analysis are given in Figure 6.

5. Discussion and Conclusion

The 2004 Baladeh-Kojur earthquake was recorded by 149 strong motion instruments belong to the Building and Housing Research Center (BHRC). The distribution of strong motion stations around the epicentral area of the 2004 Baladeh-Kojur earthquake that recorded the main shock is given in Figure 7. As indicated, there is a good coverage of strong motion instruments around the epicenter of main shock. The Iso-acceleration contour lines obtained from the recorded strong ground motions around the epicenteral area of main shock are given in Figure 8. The distribution of strong ground indicates two high acceleration areas suggesting that the main shock possibly has a multiple source characteristics or the media has amplified the ground motion. This fact should be clarified by more detailed studies in future. From the observation of damaged area in the epicentral region and the recorded strong ground motion (BHRC, 2004), it could be concluded that destruction in the highly damaged area is not uniform. Therefore, directivity and side affects as well as soil condition might control the damaged area. Thus, it is highly recommended to study this phenomena in details for the future developing plans in damaged area.

The distribution of aftershocks suggests two clustered activity and strongly suggests that the 2004 Baladeh-Kojur earthquake is a multiple source. The extent of aftershock activity indicates an average source dimension of about 40 km and the hypocenters were distributed in a depth range deep to 30 km with the highest concentration around the depth of 10-15 km. This result is consistent with the fault geometry obtained by waveform modeling.

The 2004 Baladeh earthquake consists of at least three major subevents. Waveform modelling indicates that the rupture started mainly propagated towards the west. However, field investigation suggests that fault displacement did not reach the surface, though several landslides could be observed along the fault (BHRC, 2004). Unilateral rupture process and the directivity mainly produced intense strong ground motion and extensive damage in the west. The main subevent was ruptured during the first 10 seconds. The source mechanism is explained as: (strike, dip, slip) = (130˚, 28˚, 84˚), and the total seismic moment is calculated to be $M_0= 4.1\times10^{18}$ Nm. The source duration of largest subevent is about 7 seconds and its fault length is estimated to be about 20 km. The calculated maximum dislocation is about 120 cm and the total moment magnitude is Mw = 6.3, while the estimated maximum stress drop is about 25 bar. The distribution of strong ground motion indicates two high acceleration areas. This indicates that the main shock possibly has a multiple source nature or the media has amplified the ground motion in western part of the epicentral region. This fact should be clarified by more detailed field studies in future. Although the area had been seismically active in historical times there was no evidence that earthquakes as severe as this earthquake had occurred in the vicinity of Baladeh region during at least the past 100 years. From the engineering point of view, the 2004 Baladeh-Kojur earthquake, which provided ground-motion characteristics of a rare strong event in the affected area, was the controlling event for the design of structures with high safety requirements.

Acknowledgements

The author is grateful to the Building and Housing Research Center (BHRC) of Iran for providing the near-field strong motion data. He also appreciates the critical review and helpful comments received from Prof. J. Jackson and Prof. M. Ghorashi.The teleseismic digital waveforms were copied from (IRIS-DMC) through the Internet. Prof. M. Kikuchi availed his inversion method to determine the source mechanism. The author would like to extend his warmest regards to staffs of International Institute of Seismology and Earthquake Engineering (IISEE), for cooperation during the short stay in Japan to fulfill this study. The staffs of Tehran seismic network kindly helped with the phase readings and locating the events recorded by the Tehran Network. The author is also thankful to Mr. M. Raeesi who kindly helped with providing the maps by GMT software. Discussion with him was very fruitful. This study was partially supported by the research project No.6201005/1/02 from the Institute of Geophysics and the office of the Vice Chancellor for research in Tehran University.

Table 1. The focal mechanism, the moment, the moment magnitude, and the depth of the Baladeh-Kojour earthquake obtained by USGS and the University of Harvard as well as the result of this study.

Name	Strike Dip Rake (degree)	Strike Dip Rake (degree)	M_0 (Nm)	DEP. (km)	Mw
USGS	**100 43 67**	**310 51 110**	2.5×10^{18}	**14**	**6.2**
HRVD	**116 32 69**	**321 60 103**	3.3×10^{18}	**34**	**6.3**
This study	**130 28 84**	**316 62 93**	4.1×10^{18}	**12**	**6.3**

Table 2. The seismic station code, azimuth, backazimuth, and epicentral distance of stations used in this study.

St. Code	Az	B.Az	Del
DGAR	151.5	-22.8	47.7
KBS	-9.9	133.9	45.7
SUMG	-21.3	77.6	55.8
RGN	-42.8	109.1	32.0
HLG	-45.1	102.8	34.9
RUE	-46.5	106.3	31.1
ESK	-44.8	94.0	41.4
LBNH	-36.9	42.5	84.9
IBBN	-48.3	100.0	34.6
GRFO	-52.3	99.3	32.0
TATO	79.6	-61.0	60.1
KDAK	12.7	-19.4	84.1
WLF	-53.1	94.8	35.3
STU	-54.4	96.1	33.2
INCN	64.3	-66.2	58.5
MTE	-66.0	75.2	45.8
YSS	48.8	-62.7	65.3
SFS	-71.7	72.1	45.9
CART	-71.8	75.1	41.6
MELI	-74.4	72.1	43.7
ULN	56.0	-85.0	41.9
MBAR	147.6	25.6	41.5

Table 3. The source parameters of the subevents for the final solution of the Baladeh-Kojour earthquake obtained by waveform inversion.

Subevents	Strike Dip Rake (degree)	Strike Dip Rake (degree)	M_0 (Nm)	Mw
1st subevent	121 32 74	319 59 100	2.4×10^{18}	6.2
2nd subevent	157 37 116	305 58 72	1.1×10^{18}	5.9
3rd subevent	115 20 66	320 72 98	0.6×10^{18}	5.8
Total	130 28 84	316 82 93	4.1×10^{18}	6.3

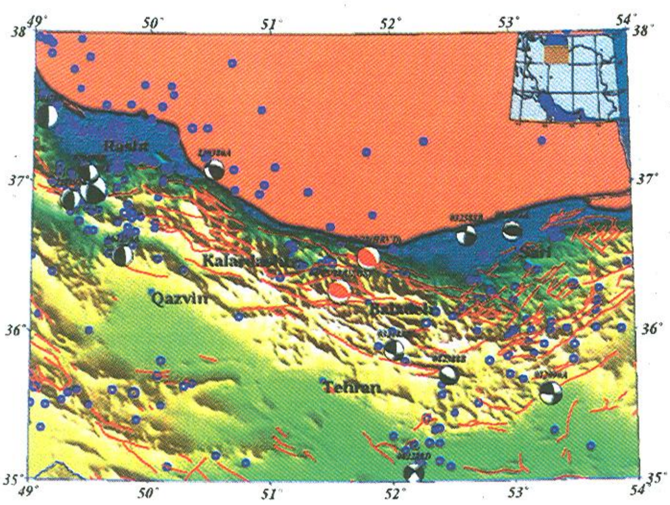

Figure 1. A simplified fault map based on Berberian (1976) and Jackson and McKenzie (1984), the location of strong earthquakes reported by ISC as well as their available fault plane solutions. The epicentral location of earthquakes is given by blue circules. The fault plane solutions given by USGS and Harvard university for the 2004 Baladeh-Kojour main shock are shown in red color.

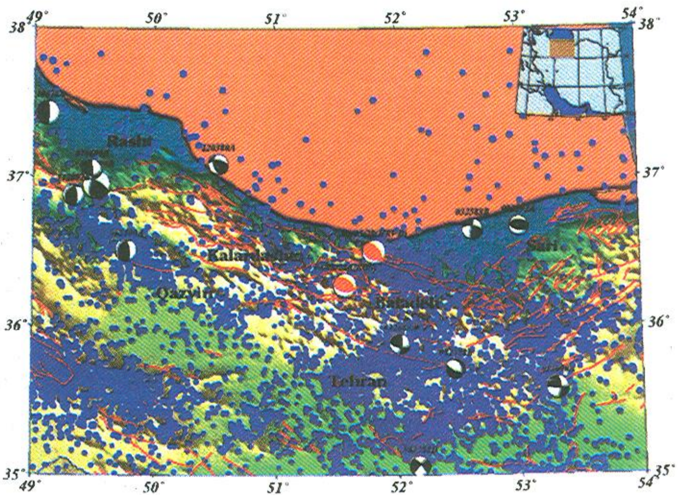

Figure 2. The epicentral distribution of locally recorded earthquakes by the ILPA seismic network during 1975-1996 are overlapped on the fault map and the available fault plane solution of strong earthquakes. The fault plane solutions given by USGS and Harvard university for the 2004 Baladeh-Kojour main shock are shown in red color.

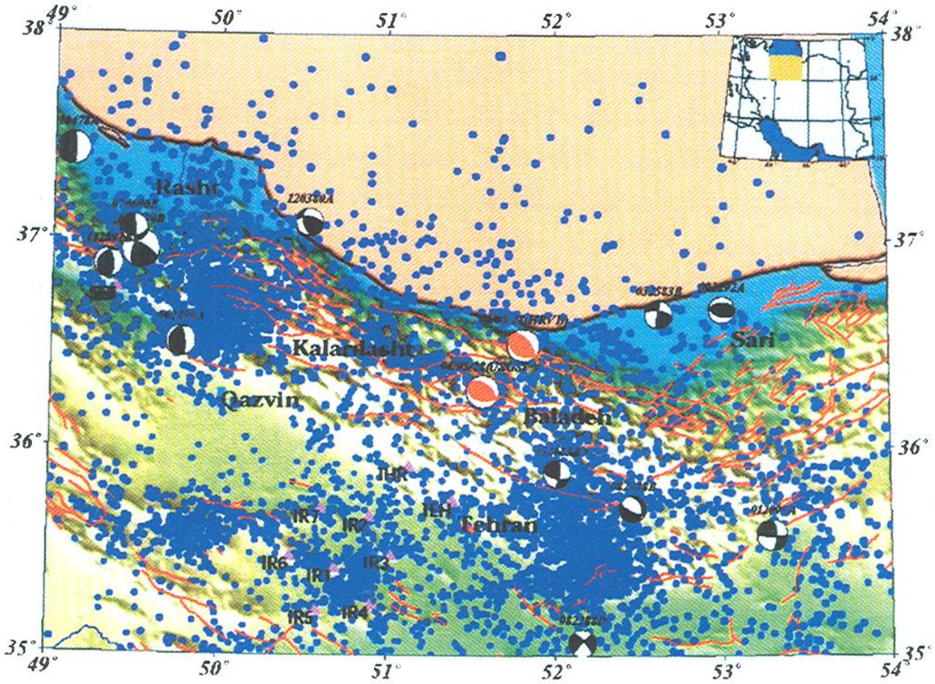

Figure 3. The epicentral distribution of locally recorded earthquakes by the Tehran seismic network during 1996-2004 are overlapped on the fault map and the available fault plane solution of strong earthquakes. The fault plane solutions given by USGS and Harvard university for the 2004 Baladeh-Kojour main shock are shown in red color.

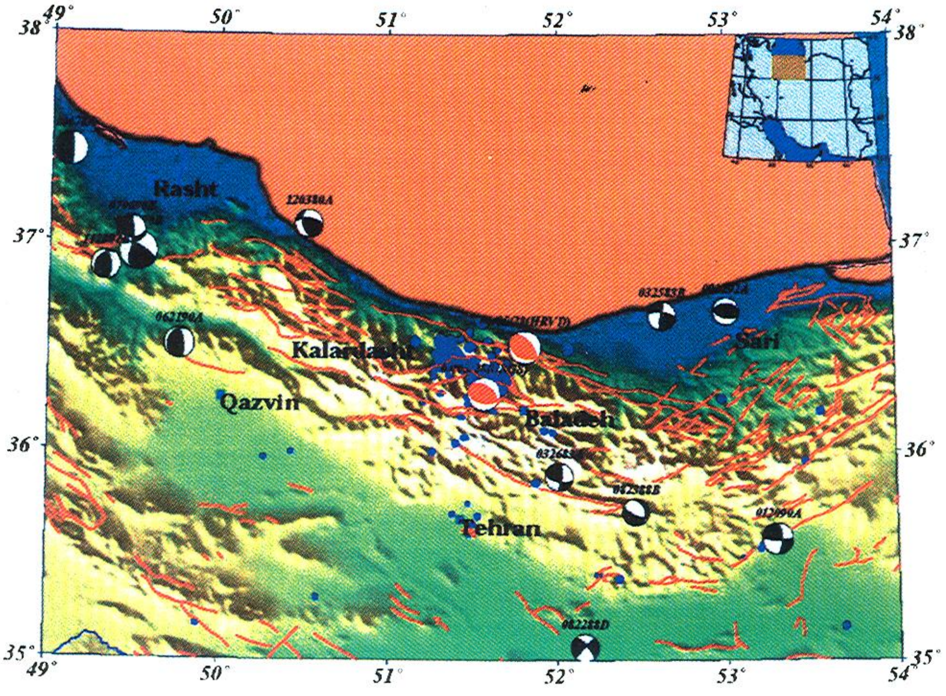

Figure 4. Distribution of aftershocks recorded by Tehran seismic stations are overlapped on the fault map and the available fault plane solution of strong earthquakes. The fault plane solutions given by USGS and Harvard university for the 2004 Baladeh-Kojour main shock are shown in red color. The epicentral distribution of aftershocks is in agreement with the observed geological faults. The extent of aftershock activity suggests a source dimension about 40 km striking NW-SE.

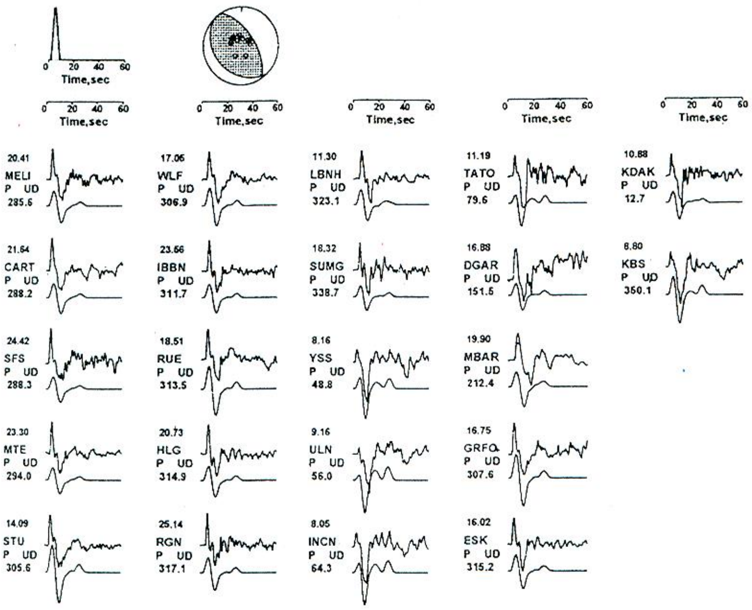

Figure 5. The source time function, the focal mechanism, and the ray directions of the stations used in this analysis as well as the comparison of the observed (top) and synthetic (bottom) waveforms after the first iteration for the 2004 Baladeh-Kojour earthquake. The correlation coefficient, name, component and azimuth of the station are given on the left side of each waveform. This figure shows that the mechanism is a pure dip-slip faulting and the correlation of observed and synthetic waveforms is acceptable.

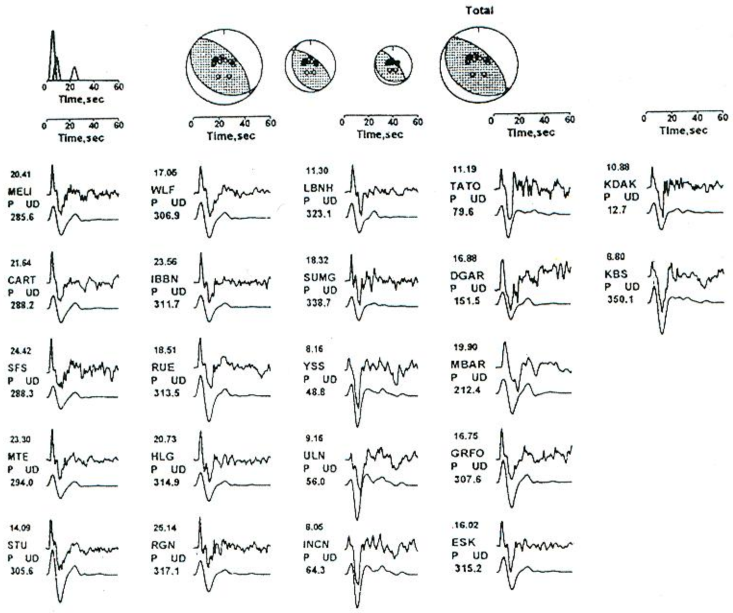

Figure 6. The source time function, the focal mechanism, and the ray directions of the stations used in this analysis as well as the comparison of the observed (top) and synthetic (bottom) waveforms for the final solutions of the 2004 Baladeh-Kojour earthquake. The correlation coefficient, name, component and azimuth of the station are given on the left side of each waveform.

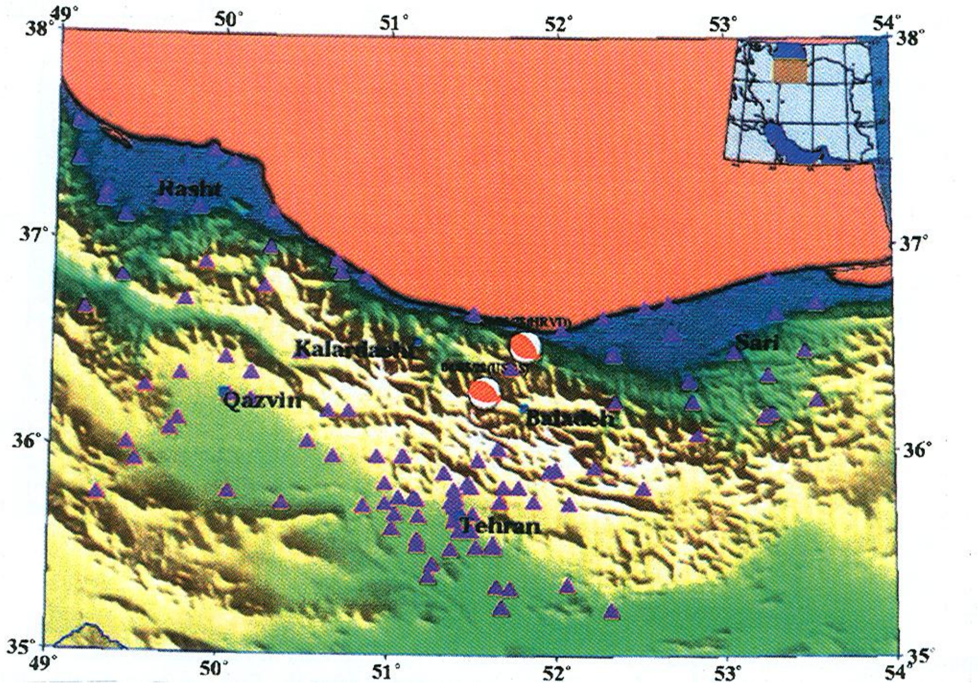

Figure 7. The distribution of strong motion stations of BHRC around the epicentral area of the 2004 Baladeh-Kojour earthquake that recorded the main shock is indicated by pink triangles. About 149 strong motion stations recorded the main shock in the region. As indicated, there is a good coverage of accelographs around the epicenter of main shock.

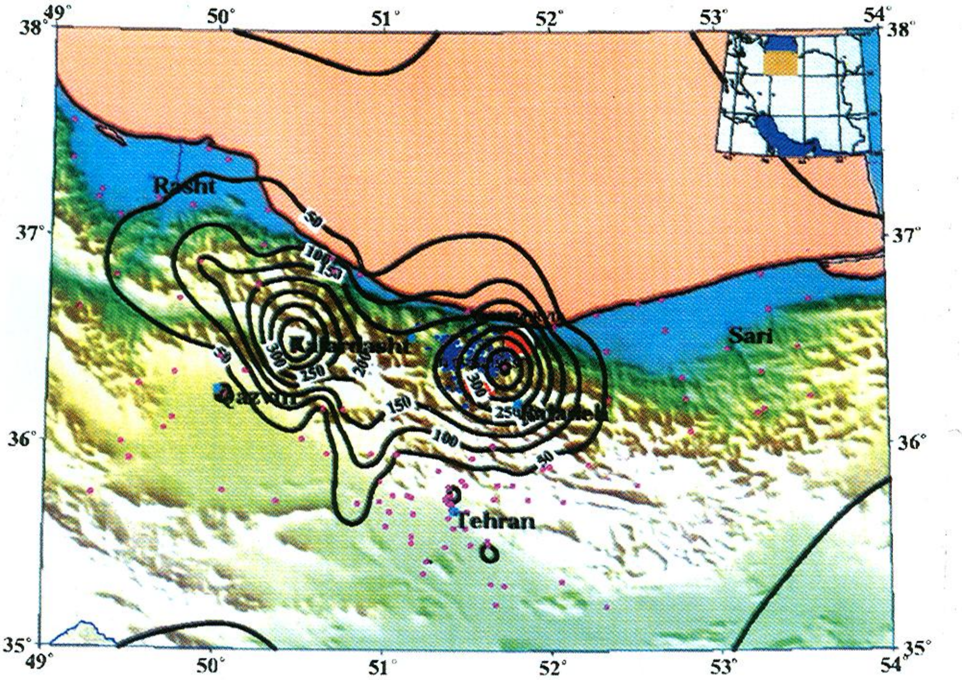

Figure 8. The Iso-acceleration contour lines obtained from the recorded strong ground motions by BHRC around the epicenteral area of the 2004 Baladeh-Kojour main shock are overlapped on the fault map, the fault plane solution of main shock and the epicenters of locally recorded aftershocks. Blue dots are the locations of locally recorded aftershocks and pink dots are locations of strong motion stations. The distribution of strong ground motion indicates two high acceleration areas, suggesting that the main shock possibly has a multiple source nature or the media has amplified the ground motion in west. This fact should be clarified by more detailed field studies in future.

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