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# CHARACTERISTICS OF 2017 HOJEDK EARTHQUAKE SEQUENCE IN KERMAN PROVINCE, SOUTHEAST IRAN

# CARACTERÍSTICAS DA SEQUÊNCIA DE TERREMOTO HOJEDK 2017 NA PROVÍNCIA DE KERMAN, SUDESTE DO IRÃ

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## ABSTRACT

Kerman province in southeast Iran, has experienced historical and instrumentally recorded earthquakes. In December 2017, three destructive earthquakes have occurred around Hojedk, in Kerman within 11 days. In this study, first the regional seismotectonics and seismicity is presented. Then, the source mechanisms of main shocks are modeled and the results are compared with the active faults and seismicity pattern is discussed. Moment tensor inversion in time domain is used to obtain the source mechanism of earthquakes. The results indicate that the mechanisms of main shocks and aftershocks are mainly reverse and are in agreement with the trend of tectonic forces as well as the mechanisms of other earthquakes. The epicentral distribution of aftershocks indicates two clusters. The spatial distributions of clusters are in agreement with the epicentral distribution of main shocks. The cluster around the first earthquake in EW cross section has a length 15-20 Km, while the cluster around the second and third has a length about 20-25 Km. The Hojedk earthquakes occurred along the northern extension of previous earthquakes where a kind of seismic gap could be observed and still exists. In 1972, within five days four earthquakes with magnitudes 5.5 to 6.2 occurred in Sefidabeh region in eastern edge of Lut block. In both regions earthquakes have reverse mechanisms and associated with surface ruptures. Thus, it could be concluded that the energy was mainly released with several moderate earthquakes in adjacent faults. In northern extensions of both regions, seismic gaps still could be observed and major earthquakes might occur in future.

**Keywords:** Hojedk Earthquakes; Moment Tensor; Source Parameters; Waveform Modeling; Focal Mechanism.

## RESUMO

A província de Kerman, no sudeste do Irã, é uma região que apresenta terremotos históricos registrados. Em dezembro de 2017, três terremotos destrutivos ocorreram em torno de

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Hojedk, em Kerman, durante o período de 11 dias. Neste estudo, em um primeiro momento é apresentada a sismotectônica regional e a sismicidade dessa região. Em seguida, os mecanismos de origem dos choques principais são modelados e os resultados são comparados com as falhas ativas e o padrão de sismicidade é discutido. A inversão do tensor de momento no tempo é usada para obter o mecanismo de origem dos terremotos. Os resultados indicam que os mecanismos dos principais choques e primários e secundários são principalmente de origem reversa e estão de acordo com a tendência das forças tectônicas, bem como com os mecanismos de outros terremotos. A distribuição epicentral dos tremores secundários indicam dois grupos. As distribuições espaciais em clusters estão de acordo com a distribuição epicentral dos choques principais. O aglomerado em torno do primeiro terremoto na seção transversal EW tem um comprimento de 15-20 Km, enquanto o aglomerado em torno do segundo e terceiro tem um comprimento de cerca de 20-25 Km. Os terremotos de Hojedk ocorreram ao longo da extensão norte do local onde foram registrados terremotos anteriores, onde uma espécie de lacuna sísmica pode ser observada e ainda existente. Em 1972, em cinco dias, quatro terremotos com magnitudes de 5,5 a 6,2 ocorreram na região de Sefidabeh na borda leste do bloco de Lut. Em ambas as regiões, os terremotos têm mecanismos reversos e associados a rupturas de superfície. Assim, pode-se concluir que a energia foi liberada principalmente com vários tremores moderados em falhas adjacentes. Em extensões ao norte de ambas as regiões, lacunas sísmicas ainda podem ser observadas e grandes terremotos podem ocorrer no futuro.
**Palavras-chave:** Terremotos de Hojedk; Tensor de momento; Parâmetros de fonte; Modelagem de forma de onda; Mecanismo Focal.Introduction

## INTRODUCTION

Kerman region in southeast Iran, covers a part of central Iran and Lut Block. In this region, many historical earthquakes have been reported (AMBRASEYS, MELVILLE, 1982). In present century, many destructive earthquakes have been recorded by seismic networks. The 1977 Gisk earthquake with magnitude 5.9 (BERBERIAN *et al.*, 1979), the 1981 Golbaf-Sirch earthquakes with magnitudes 6.9 and 7.2 (GHEITANCHI, 1999), The 1998 Fandoga earthquake with magnitude 6.8 (GHEITANCHI, 2002), the 2003 Bam earthquake with magnitudes 6.6 (TALEBIAN *et al.*, 2004), the 2005 Zarand earthquake with magnitude 6.4 (TALEBIAN *et al.*, 2006) and the 2010 and 2011 Rigan earthquakes with magnitudes 6.5 and 6.2 (WALKER *et al.*, 2013) suggest the existence of active faults and high seismic activity in the region.

In November 2017 within 12 days three destructive earthquakes have occurred in Kerman province. The first earthquake (30.74N, 57.37E, h=8 km, Mn 6.2; IGTU) occurred on 1th December at 02h 32m 44s GMT, 06h 02m 44s local time, in the sparsely populated region of Hojedk area not far from the epicenter of the Zarand destructive earthquake that has occurred in 2005 in Kerman province, southeast Iran. The second earthquake (30.71N, 57.33E, h=8 km, Mn 6.2; IGTU) occurred on 12th December at 08h 43m 16s GMT, 12h 13m 16s local time. The third earthquake (30.80N, 57.31E, h=8 km, Mn 6.0; IGTU) occurred on 12th December at 21h 41m 29s GMT, 01h 11m 29s local time. The earthquakes did not produce human loss but frightened local people and caused extensive damage. In this study, first the seismicity and seismotectonics of the region were reviewed. Then, the mechanisms of mainshocks were modeled and the results were discussed with the active faults of the region. Moment tensor inversion in time domain was used to obtain the mechanism of earthquakes in the study region.

## ACTIVE FAULTS OF THE REGION

Kerman region, in southeast Iran, covers a part of central Iran and Lut block. Most of this region is tectonically active. A part of convergence motion between Eurasia and Arabian plate is saturated along the right lateral active fault in the region. Kerman province includes Golbaf or Gowk fault which is one of most active faults in Kerman with a length about 100 Km and has a NW-SE trend. This fault has experienced more than 13 historical and instrumentally recorded earthquakes with magnitudes greater than 5 (AMBRASEYS, MELVILLE, 1982). Nayband fault is another active fault with a length 400 Km and maximum vertical offset about 20 m. The southern part of this fault has experienced strong earthquakes indicating that this fault is seismically active. The next active fault is north-south trending Lakarkouh fault nearly parallel to Nayband fault and has a length about 130 km. The 1290 destructive earthquake in Lavar that killed 700 people was related to this fault. The other active fault is Kuhbanan fault with NW trend which is initiated from west Kerman city and extended to northwest of Behabad with a length about 300 km. This fault is one of seismically active faults in Kerman province (AMBRASEYS, MELVILLE, 1982).

**DATA ANALYSIS**

In this study, the recorded broadband data by Institute of Geophysics in Tehran University (IGTU) and International Institute of Earthquake Engineering and Seismology (IIEES) were used to obtain source mechanisms. First instrument correction was applied to all waveforms data by using bandpass filter from 0.01 to 0.06 Hrz. Using discrete wave number method, Green functions were calculated (BOUCHON, 1981) and synthetic seismograms were obtained. Then, inversion was conducted by linear combination of base seismograms and six moment tensor components (ZAHRADNIK *et al.*, 2005).

To obtain the source parameters of first earthquake that occurred on 1th December at 02h 32m 44s GMT, 06h 02m 44s local time, recorded data from five broad band national seismic stations were used. Using least square method inversion procedure, linear combination of base seismograms and five moment tensor elements was applied (KIKUCHI, KANAMORI, 1991). To obtain centroid depth, first we search for best fit of depth beneath the epicenter along a vertical line. Then, we look for best fit on a horizontal plane by grid search. The best depth for first earthquake was estimated about 11 km. The correlation curve for depth estimation with 1 km intervals is given in Figure 1. Correlation between observed and synthetic seismograms are given in Figure 2. The focal mechanisms obtained in this study are mainly reverse. The trend of principle stress has north to northeast direction. The location and mechanisms of three Hojedk earthquakes as well as main faults are given in Figure 3.

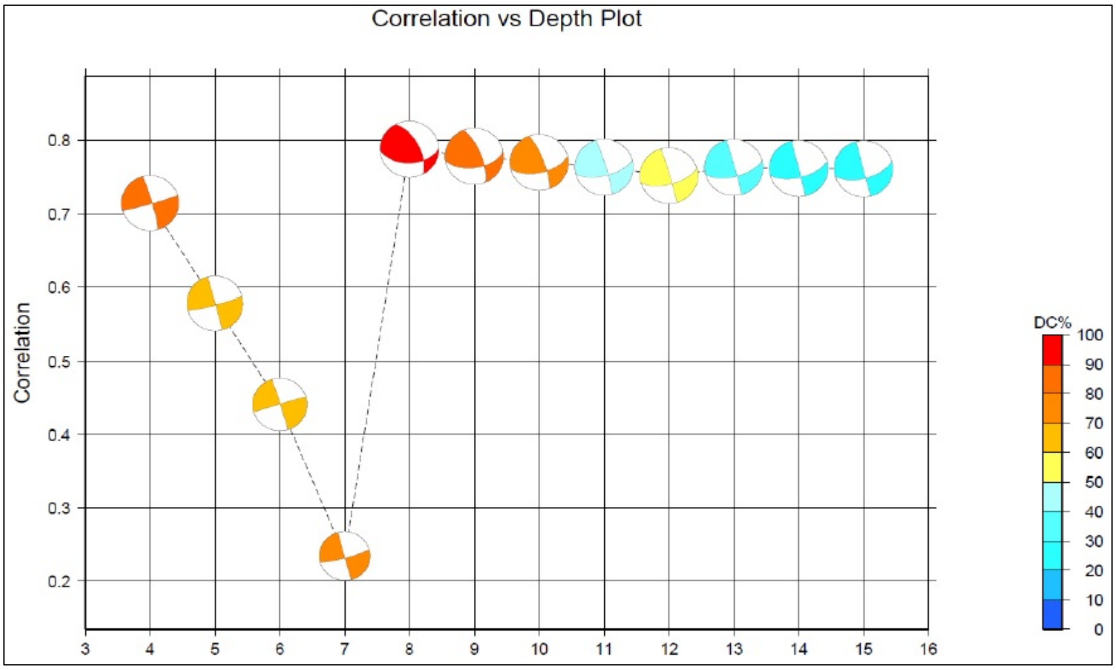


*Figure 1*. Correlation-Depth diagram for the first earthquake. Horizontal axis indicates depth in km and vertical axis indicates correlation coefficient. Depth for first earthquake is estimated 8 km.
Source: Elaborated by the authors (2020).

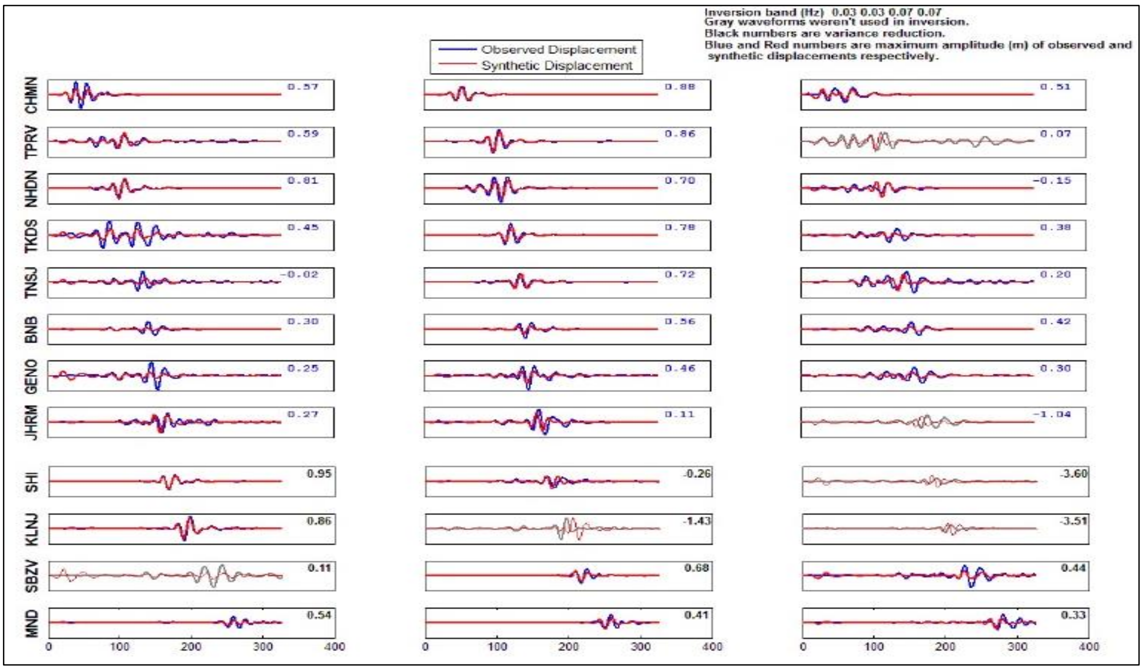


*Figure 2*. Correlation between observed and synthetic seismograms for the first earthquake. Horizontal axis indicates time in seconds and vertical axis indicates displacement. Station code is given in left column. Correlation coefficients are given at top right of seismograms.
Source: Elaborated by the authors (2020).

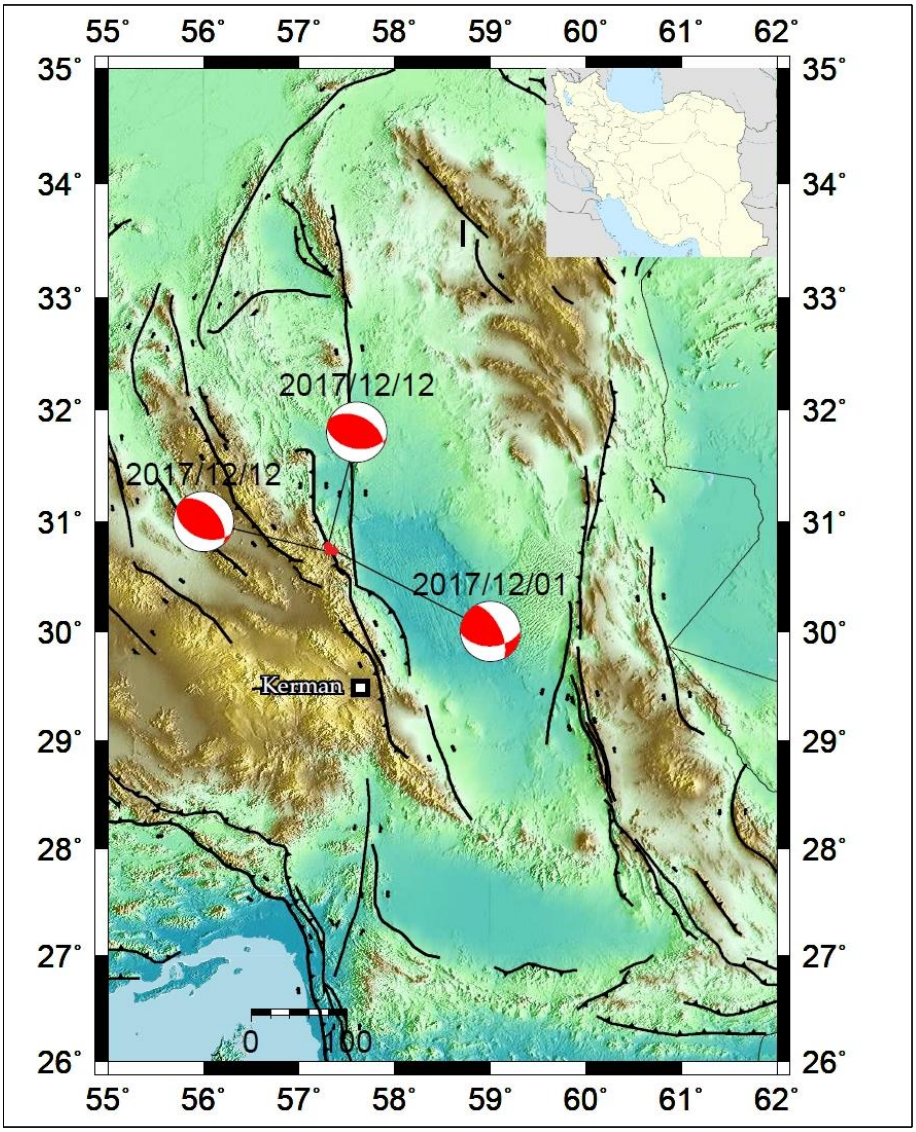


*Figure 3*. Epicentral distribution and mechanism of mainshocks and aftershocks that were obtained with waveform modeling in this study. Solid triangles are seismic stations. The mechanisms of earthquakes are mainly reverse and the principle stress has a N-NE trend.
Source: Elaborated by the authors (2020).

To obtain the source parameters of second earthquake that occurred on 12th December at 08h 43m 16s GMT, 12h 13m 16s local time, recorded data from five broad band national seismic stations were used. Using the same method, the best depth for second earthquake was estimated about 11 km. The correlation curve for depth estimation with 1 km intervals is given in Figure 4. Correlation between observed and synthetic seismograms are given in Figure 5. The focal mechanisms obtained in this study are mainly reverse. The trend of principle stress has north to northeast direction.

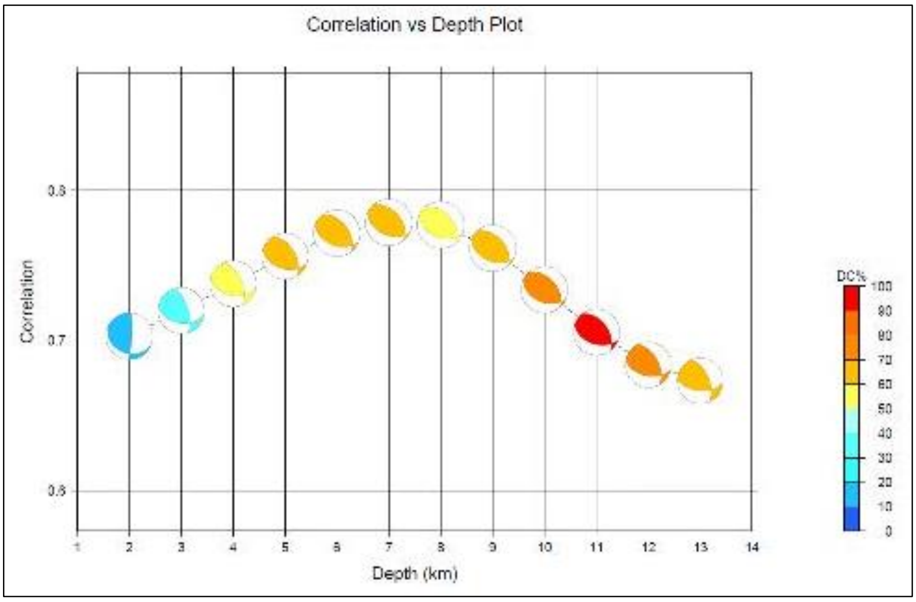


*Figure 4*. Correlation-Depth diagram for the second earthquake. Horizontal axis indicates depth in km and vertical axis indicates correlation coefficient. Depth for second earthquake is estimated about 11 km
Source: Elaborated by the authors (2020).

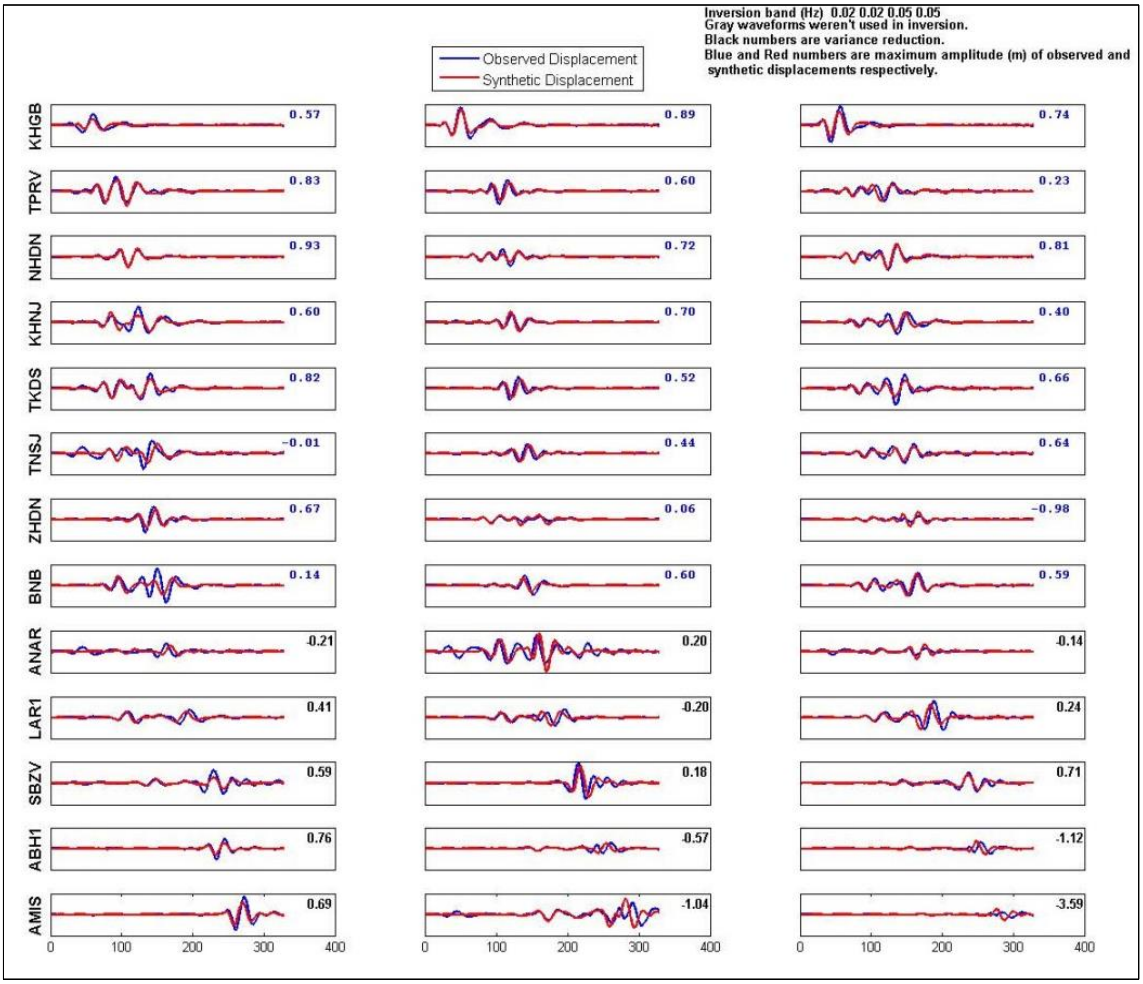


*Figure 5*. Correlation between observed and synthetic seismograms for the second earthquake. Horizontal axis indicates time in seconds and vertical axis indicates displacement. Station code is given in left column. Correlation coefficients are given at top right of seismograms.
Source: Elaborated by the authors (2020).

Using the same method, we obtained the source parameters of third earthquake that occurred on 12th December at 21h 41m 29s GMT, 01h 11m 29s local time. The best depth for second earthquake was estimated about 3 km. The correlation curve for depth estimation with 1 km intervals is given in Figure 6. Correlation between observed and synthetic seismograms are given in Figure 7. The focal mechanisms obtained in this study are mainly reverse. The trend of principle stress has north to northeast direction.

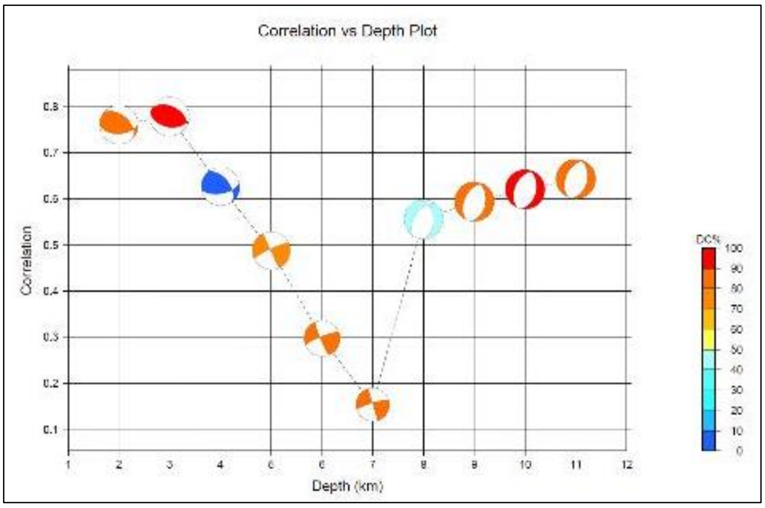


*Figure 6*. Correlation-Depth diagram for the third earthquake. Horizontal axis indicates depth in km and vertical axis indicates correlation coefficient. Depth for third earthquake is estimated about 3 km. Source: Elaborated by the authors (2020).

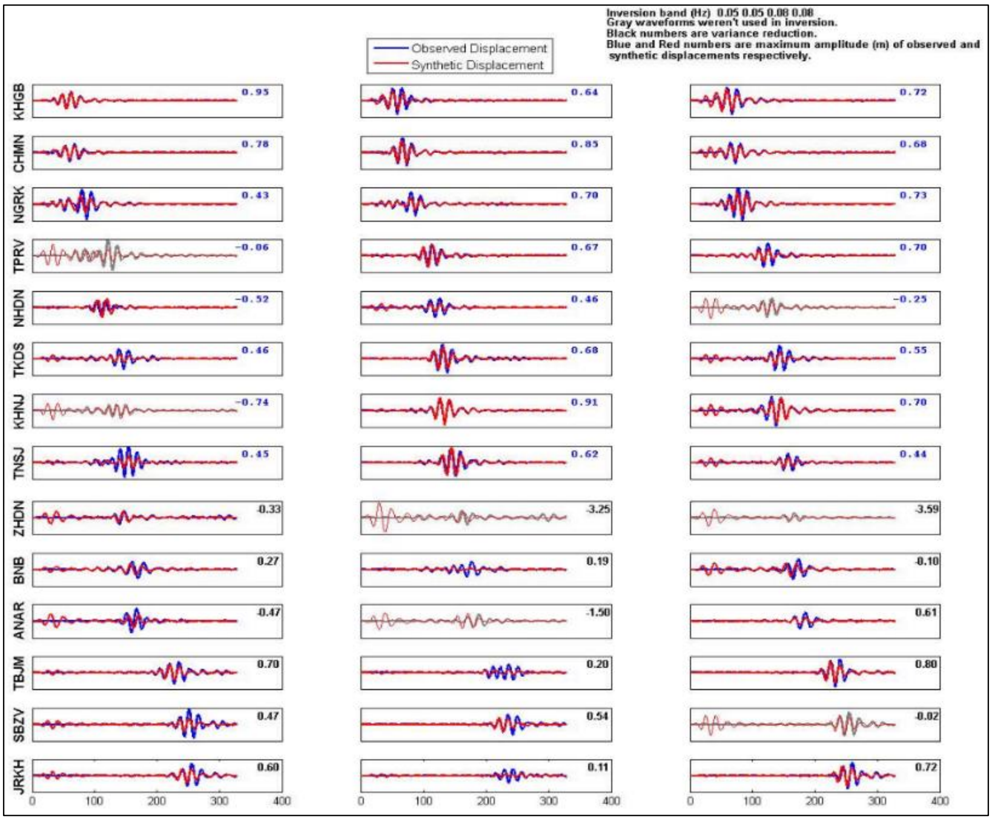


*Figure 7*. Correlation between observed and synthetic seismograms for the third earthquake. Horizontal axis indicates time in seconds and vertical axis indicates displacement. Station code is given in left column. Correlation coefficients are given at top right of seismograms.
Source: Elaborated by the authors (2020).

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**AFTER SHOCKS STUDY**

Hojedk earthquakes were followed by many aftershocks. Within 40 days about 800 aftershocks with magnitudes larger than 2.5 were reported by IGTU. Time-Frequency diagram of mainshocks and aftershocks is given in Figure 8. Time-Magnitude diagram of mainshocks and aftershocks is given in Figure 9. Time-Space diagram of mainshocks and aftershocks is given in Figure 10. The horizontal axis is time in days and the vertical axis is the horizontal cross section. The cluster of aftershocks around the first earthquake in cross section suggests a length about 15-20 km. While, the cluster of aftershocks around the second and third earthquakes in cross section suggests a length about 20-25 km. Epicentral distribution of mainshocks and aftershocks with magnitudes larger than 4 is given in Figure 11. Mechanism of mianshocks and aftershocks with magnitudes larger than 4 obtained by waveform modeling is given in Figure 12. Mechanisms of aftershocks are mainly reverse and are in agreement with the mechanisms of mainshocks. This indicates that aftershocks were mainly occurred around the causative faults of mainshocks.

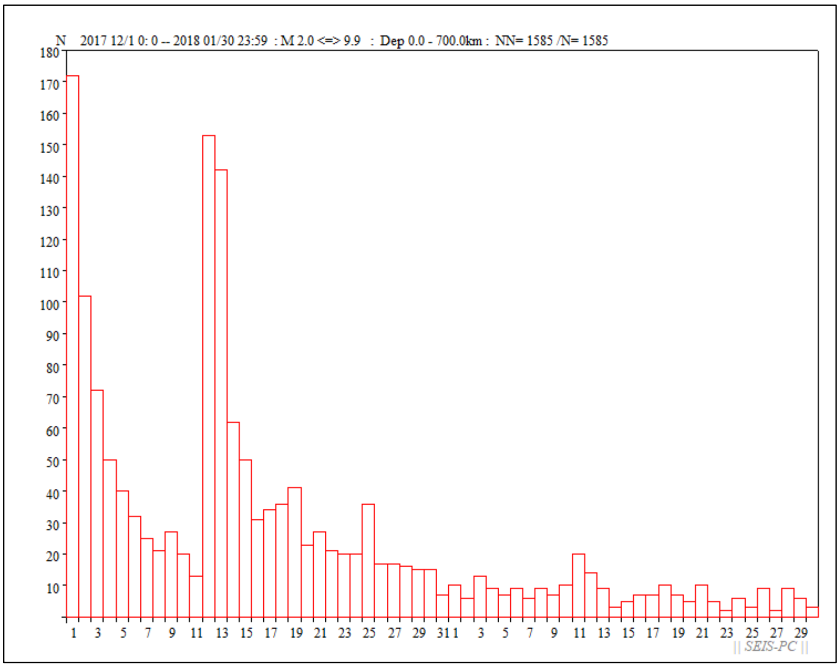


*Figure 8*. Time-Frequency diagram for Hojedk earthquake sequence. Horizontal axis indicates time in days and vertical axis indicates the frequency of earthquakes.
Source: Elaborated by the authors (2020).

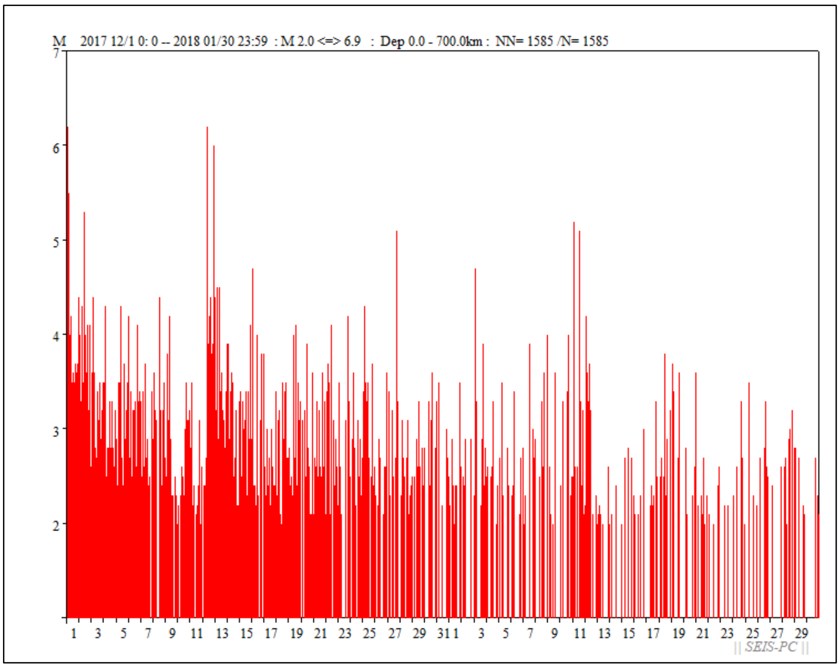


*Figure 9*. Time-Magnitude diagram for Hojedk earthquake sequence. Horizontal axis indicates time in days and vertical axis indicates magnitude. Within two months 1585 aftershocks were reported by IGTU.
Source: Elaborated by the authors (2020).

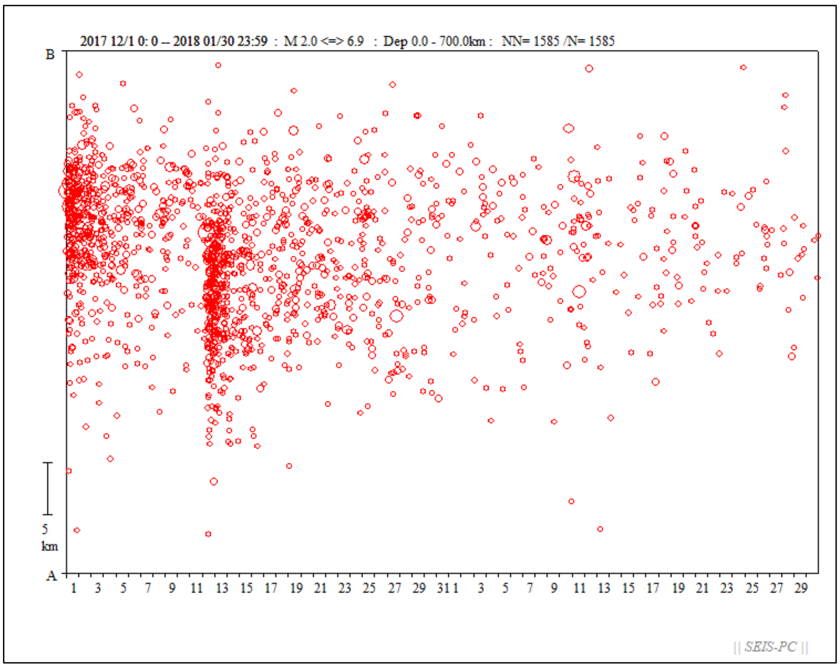


*Figure 10*. Time-Space diagram for Hojedk earthquake sequence. Horizontal axis indicates time in days and vertical axis indicates cross section in km.
Source: Elaborated by the authors (2020).

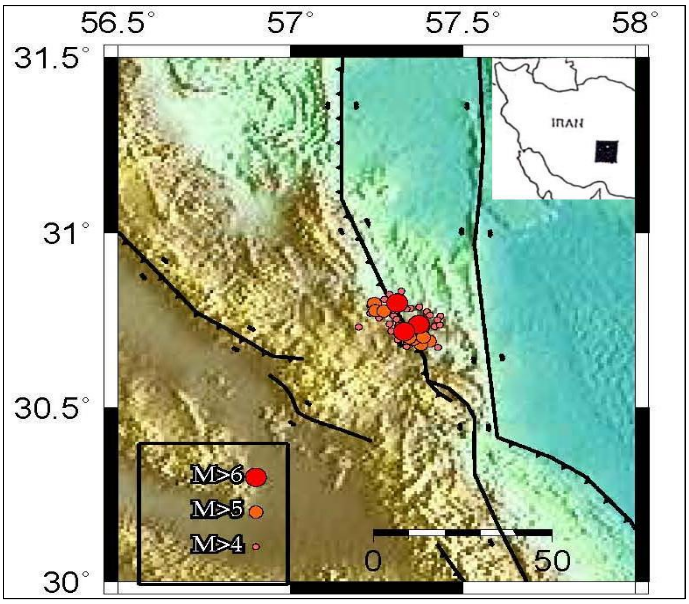


*Figure 11*. Epicentral distribution of mainshocks and aftershocks with magnitudes greater than 4. Mainshocks are given in red circles. Distribution of aftershocks indicates two clusters around the epicenters of mainshocks.
Source: Elaborated by the authors (2020).

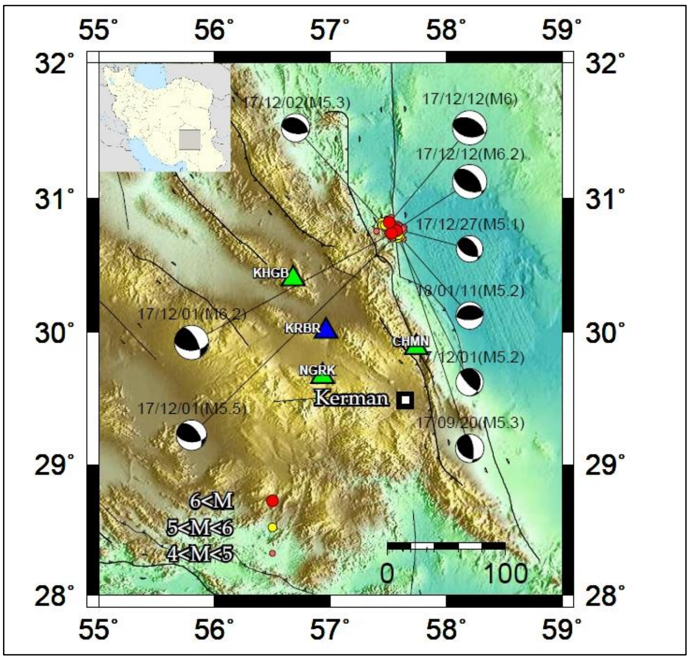


*Figure 12*. Epicentral distribution and mechanism of mainshocks and aftershocks that were obtained with waveform modeling in this study. Solid triangles are seismic stations. The mechanisms of earthquakes were mainly reverse and the principle stress has a N-NE trend.
Source: Elaborated by the authors (2020).

## DISCUSSION AND CONCLUSION

In this study, the recorded waveforms in national seismic broadband stations for three Hojedk earthquakes were modeled. The mechanisms of earthquakes obtained in this study are mainly reverse and are in agreement with the trend of tectonic forces and mechanism of other earthquakes in the study region. The mechanisms of aftershocks are mainly reverse and are consistent with the mechanism of mainshocks. The epicentral distribution of aftershocks indicates two clusters in two areas. The locations of clusters are in agreement with the epicenters of mainshocks. The cluster of aftershocks around the first earthquake in cross section suggests a length about 15-20 km and around the second and third earthquakes in cross section suggests a length about 20-25 km. Occurrence of three destructive earthquakes within 11 days is a rare seismic activity in this region. The Hojedk earthquake occurred along the north extension of previous earthquakes in Kerman province, in a region that a kind of seismic gap could be observed. Regarding the epicentral distribution of mainshocks and aftershocks in Hojedk, it could be concluded that along the north section of Hojedk still seismic gap could be observed and the occurrence of significant earthquake is not out of expectation. Four destructive earthquakes occurred in 1994 in Sefidabeh along the western boundary of Lut Block. The earthquake activity in Hojedk is comparable with the 1994 activity in Sefidabeh. In both regions earthquakes with same sizes and similar mechanisms occurred in shot time intervals. In both cases earthquakes have mostly associated with surface ruptures. It could be concluded that in both regions, energy was released by several moderate earthquakes. Epicentral distribution of earthquakes indicates that a kind of seismic gaps exists and earthquakes possibly would occur in both regions. The Hojedk earthquakes occurred in Ravar city, north of Kerman province. This region has not experienced historical earthquake. The mechanisms of earthquake that obtained in this study are reverse and the principle stress has a N-NE trend.

**ACKNOWLEDGMENTS**

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