Attenuation of seismic waves in Gheshm region, southeast Iran

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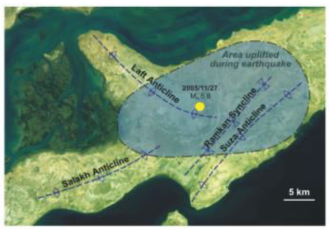
Abstract

Coda quality factor (Q_c) was estimated for the Gheshm Island region in southern Iran by using aftershock data of the Gheshm earthquake of 27 November 2005, recorded within an epicentral distance of 100 km. More than 2000 earthquakes were recorded by the International Institute of Earthquake Engineering and Seismology (IIEES) local temporary network consisting of 13 broadband seismic stations installed for three month after the main event. Q_c was estimated based on the single backscattering approximation in frequency bands of 1–20 Hz. To investigate the lateral variation, Q_c was calculated for all the stations and in different parts of the study area. The lowest values were derived in the western part with an average frequency relation of $Q_c = 74 f^{0.81}$ and the highest values in the eastern part with an average frequency relation of $Q_c = 88 f^{0.78}$, but generally there is an absence of significant lateral variation in coda Q. The average frequency relation for this region is $Q_c = 77 f^{0.83}$ and Q_c increases with depth; however, the increasing rate is not uniform. This study along with the results of previous works in the west-northwest of the study area (Farahbod & Gheitanchi, 1997; Rahimi & Hamzehloo, 2008 and Gholamzadeh et al., 2014) and in the northeast of Gheshm Island (Farahbod et al., 2004) represents a close relationship between tectonics and coda Q.

Study Background

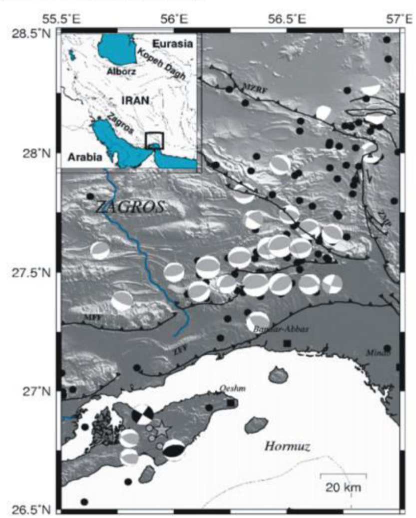


An earthquake with magnitude Mw 5.8 occurred on Gheshm Island, in the western edge of the Strait of Hormuz in SE Zagros, on November 27, 2005. This earthquake destroyed 3 villages completely and killed 10 persons. An interesting feature of this earthquake is the strike-slip mechanism of the strongest aftershock (Mw 5.4) that occurred roughly 6 hours after the mainshock, which is completely different from the pure reverse mechanism of the mainshock.

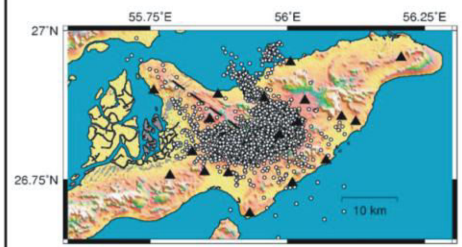
Very little is known about the seismicity of this region. Historically, only one moderate event, in 1361, occurred on the Gheshm Island but it is not well documented (Ambraseys and Melville,1982). Also Engdahl et al. (2006) reported few well-located earthquakes in their catalogue near the island in recent decades. Therefore, information from the November 27 earthquake and its aftershocks in terms of source location and attenuation characteristics may help to improve our knowledge about the seismotectonic framework of this seismically quiet part of the Zagros Mountains.

Geological Setting-Zagros Active Faulting

The Zagros Mountains extend for about 1700km from NE Turkey to the Strait of Hormuz, where the north–south trending Zendan-Minab-Palami fault system separates the Zagros Mountains from the Makran accretionary prism. The northeastern edge of the Zagros Mountains is marked by the Main Zagros Reverse Fault which forms a steeply NE-dipping to sub-vertical reverse fault with a right-lateral component of movement (Stöcklin, 1974; Berberian, 1995). There is no clear surface boundary to the frontal edge of the Zagros deformation front, however, the southern edge of the Zagros front can be defined by the seismicity and topography. Deformation within the Zagros Mountains is due to the relative convergence between Arabia and Eurasia since the Late Cretaceous, however, the Zagros mountain belt formed during the main phase of the Zagros orogeny in Late Miocene to recent times (Stoneley, 1981; Hessami et al., 2001). Current shortening at a rate of about 7mm/y (Hessami et al., 2006) as well as active seismicity indicate that this deformation is still active. Most focal mechanism solutions of earthquakes in the Zagros Mountains indicate the presence of active reverse faults in the basement. Strike-slip faults in the basement beneath the sedimentary layer of the Zagros Mountains have also been inferred from seismological evidence and from the associated lateral offset of fold axes observed on geological maps and satellite images. The presence of strike-slip faults in the Zagros basement suggests that some of the convergence between Arabia and Eurasia is accommodated by rotation of fault-bounded blocks about vertical axes and extension of the crust along the strike of the belt as well as by crustal shortening and thickening along thrust faults.



Local Temporary Network-Aftershock Distribution



To study the aftershock sequence, a dense temporary network of 17 short-period seismographs was deployed by the International Institute of Earthquake Engineering and Seismology (IIEES) around the epicentral zone for almost 10 weeks (from December 2, 2005 to February 26, 2006) . 2617 events recorded by at least three stations were extracted from the continuous data and located (Yaminifard et. al., 2012).

After initial processing, all events were located using a velocity model provided for the Zagros region (Hatzfeld et al., 2003). To improve the velocity model, a subset of 295 events was selected which recorded by at least 10 stations with an azimuthal gap less than 180°, an RMS less than 0.2 s and uncertainties in epicenter and depth of less than 2 km. With these criteria the trade off between the velocity structure and the location of the events is small. Plotting Tsj -Tsi (s arrival time to stations i and j, respectively for same event) versus Tpj -Tpi (p arrival time to stations i and j, respectively for same event) a Vp/Vs ratio of 1.85 from 2544 arrival times was calculated (Yaminifard et. al., 2012). Also a velocity model developed using the program VELEST (Kissling, 1988).

Coda Q Analysis Of The Aftershocks

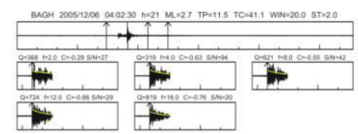
We determine the coda Q, or Q_c, using the single backscattering approximation, which assumes that the *S* coda waves comprise secondary *S* waves produced by heterogeneities inside the propagation medium (Aki, 1969; Aki and Chouet, 1975). The coda wave amplitude *A* at frequency *f*, and lapse time *t* (time from the event origin) is described by:

$$A(f, t) = S(f) t^{-\beta} e^{-\pi f t / Q_c} \quad (1)$$

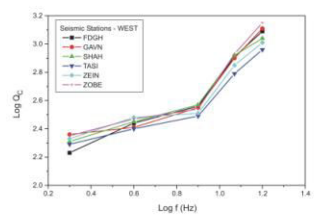
where $S(f)$ is the source factor, which is related to the earthquake source spectrum and includes station site, backscattering, and source effects (Wu and Aki, 1988), and β is a geometrical spreading parameter. Equation (1) assumes that the source and receiver are at the same point, which is only a good approximation for signals at a lapse time, *t*, greater than twice the *S*-wave travel time, t_s (Sato, 1977; Rautian and Khalturin, 1978). For body-waves (this study) β= 1 and equation (1) can be written as:

$$\ln(A(f,t)) + \ln(t) = \ln(S(f)) \quad \pi f t / Q_c \quad (2)$$

Plotting the envelope of $\ln(A(f,t)) + \ln(t)$ as a function of *t* for a given frequency (by band pass filtering the signal), gives a straight line with slope $\pi f / Q_c$ and Q_c can be determined (Havskov and Ottemöller, 2010). By calculating the Q_c values for different frequencies, the frequency dependence of this quantity can be expressed as $Q_c = Q_0 f^{\alpha}$ (Rautian and Khalturin, 1978) with Q_0 and α obtained by linear regression of log (Q_c) on log (*f*).



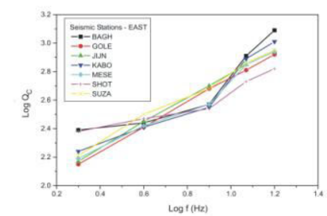
Data processing example for an earthquake beneath Gheshm Island recorded on December 06, 2005. The first step is a visual inspection of available waveforms and the selection of the closest stations to the event with the highest S/N ratio. The top trace is the original unfiltered waveform where the 3 vertical lines indicate (from left) origin time, start and end of coda window. Above the seismogram is first the station code, origin time, depth (h), magnitude (ML), P-wave travel time (TP, s), start of coda window from the origin (TC, s), window length (WIN, s) and start of coda window in terms of S-wave travel time (t coda > ST*S-travel time). The amplitude decay corresponding to estimation parameters (f: frequency, C: correlation coefficient and SN: signal to noise ratio) are shown by a curve in the five filtered segment.



Logarithmic plots of the overall average variation of coda Q with frequency (west and east of the mainshock area).

$Q = 75 f^{0.81}$ (West)

$Q = 89 f^{0.78}$ (East)



Conclusions: Q_c was calculated for all the stations and in different parts of the study area. The lowest values were derived in the western part with an average frequency relation of $Q_c = 74 f^{0.81}$ and the highest values in the eastern part with an average frequency relation of $Q_c = 88 f^{0.78}$, but generally there is an absence of significant lateral variation in coda Q. The average frequency relation for this region is $Q_c = 77 f^{0.83}$.