SOURCE PARAMETERS OF THE APRIL, 16, 2013, SARAVAN IRAN GREAT EARTHQUAKE USING SPECTRA OF P AND S WAVES

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ABSTRACT

On 16th April 2013 at 10:44 AM UTC, a great earthquake struck the Saravan region in South eastern Iran. The Mw was assessed to be 7.8 and a depth of 63km was assigned by IIEES. According to the deep depth of this event, this event can be associated with subduction of oceanic lithosphere of Arabian plate beneath the Makran ranges. Saravan earthquake was recorded at stations of Iranian National Broad-Band Seismic Network (INSN). In this study we determined source parameters of Saravan earthquake include seismic moment, corner frequency, source radius and stress drop using displacement spectra of P and S waves observed at 16 stations of INSN. The spectra of the records were corrected for attenuation then source parameters retrieved by fitting a Brune's point source model. The average stress drops obtained here for P and S waves are 131 and 149 bars respectively. The larger average values of stress drop estimated for Saravan earthquake in comparison with median stress drop values obtained from previous studies for other regions of Iran can be related to different tectonic setting of the region.

INTRODUCTION

At 10:44 UTC (15:14 local time), April 16, 2013, an earthquake struck the Saravan region in South eastern Iran. The Mw was assessed to be 7.8 and a depth of 63km was assigned by IIEES. The focal mechanism is found to be mostly extension faulting and the fault trend is evidently ENE-WSW The earthquake had reportedly 41 victims and more than 180 injured people. One of the victims was reported from Iran (in the village of Ghader abad of the city of Khash) and the 40 others were reported from Pakistan. According to the deep depth of this event, this event can be associated with subduction of oceanic lithosphere of Arabian plate beneath the Makran ranges (Zare et al, 2013). Makran is part of the coastal territory of Iran and Pakistan and stretches for ~1000 km from the Strait of Hormoz, in the south of Iran, to near Karachi in Pakistan (Fig. 1) (Shah-hosseini et al, 2011). The Makran subduction zone is unusual in several respects: the eastern and western halves of Makran exhibit very different patterns of seismicity, have historic records with and apparently without great events, respectively, and both segments are the site of one of the world's largest forearc region (Byrne et al, 1992). The seismicity associated with the Makran is low compared to other subduction zones, and there is no well-developed Benioff zone apparent (Musson , 2009). Seismicity of the region from 1905 to 2015 is shown in Fig. 2.

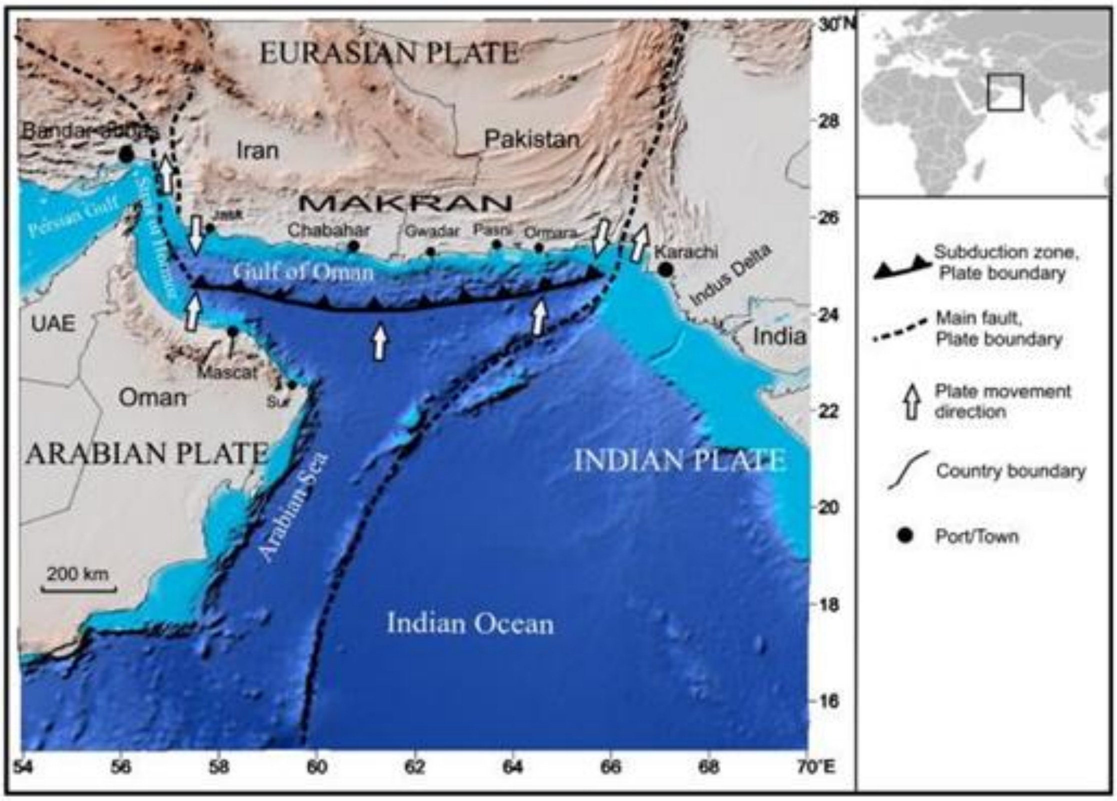


Figure 1. Tectonic setting of Makran in the northern Indian Ocean (Shah-hosseini et al, 2011).

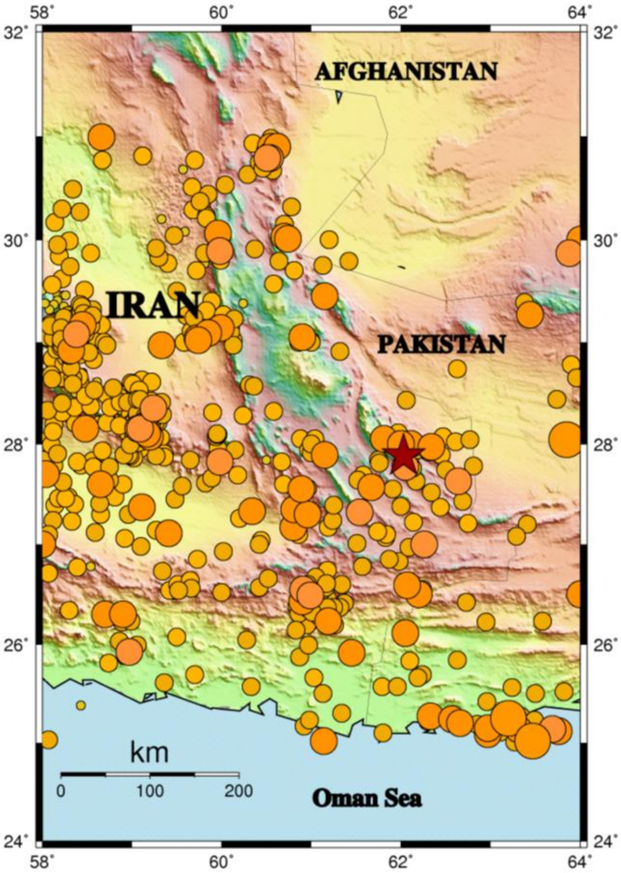


Figure 2.Seismicity of the region from 1905 to 2015.The star indicates the epicenter of Saravan earthquake.

The aim of the present article is to estimate source parameters of Saravan earthquake include seismic moment, corner frequency, source radius and stress drop using displacement spectra of P and S waves recorded at Iranian National Broad-Band Seismic Network (INSN). The spectral amplitudes of the records were corrected for attenuation and geometrical spreading functions then source parameters retrieved assuming a Brune's point source model and the results are compared with those obtained previously by other studies.

METHODOLOGY AND RESULTS

Different source parameters, such as seismic moment (M_0), corner frequency (f_0) and stress drop ($\Delta\sigma$), can be estimated by fitting an ω^2 model to the P or S wave spectra.

The Brune model (Brune, 1970) predicts the following source displacement spectrum S(f):

$$S(f)=\frac{M_0}{\left(1+\left(\frac{\mathrm{f}}{\mathrm{f}_0}\right)^2\right)4\pi\rho v^3} \qquad (1)$$

where M_0 is the seismic moment, ρ is the density, v is the velocity at the source (P or S-velocity depending on spectrum) and f_0 is the corner frequency. The displacement spectrum at an epicentral distance Δ and depth h can be expressed as:

$$D(f,t)=\frac{M_0\times 0.6\times 2.0}{\left(1+\left(\frac{\mathrm{f}}{\mathrm{f}_0}\right)^2\right)4\pi\rho v^3}G(\Delta,h)A(f,t) \qquad (2)$$

where t is the travel time, the factor 0.6 account for average radiation pattern effect, the factor 2.0 is the effect of the free surface, $G(\Delta,h)$ is geometrical spreading and $A(f,t)$ is attenuation function (Havskov and Ottemoller , 2010).

As we know the attenuation affects the shape and the level of the spectrum that can change the corner frequency and the seismic moment respectively if does not remove from the spectrum. The spectrum corrected for attenuation is used to obtain the observed parameters corner frequency f_0 and spectral flat level Ω_0. In case of 1/r body wave spreading the seismic moment can then be calculated as:

$$M_0=\frac{\Omega_0 4\pi\rho v^3 r}{0.6\times 2.0} \qquad (3)$$

For a circular fault, the source radius *a*, is calculated as:

$$a=\frac{kv_s}{f_0} \qquad (4)$$

Where *a* is the fault radius, *k* is a constant that depends upon the specific theoretical model and v_s is S wave velocity. The static stress drop (average across fault area) is calculated as (Eshelby, 1957):

$$\Delta\sigma=\frac{7}{16}M_0\frac{1}{a^3} \qquad (5)$$

Thus using corner-frequency measurements, together with measurements of M_0, stress drop can be estimated from far-field spectra.

In this study to estimate source parameters of Saravan earthquake we use three-component waveforms recorded at 16 stations of Iranian National Broad-Band Seismic Network (INSN). Displacement spectra of P and S waves at each station were made separately using a proper time window length in which the signal to noise ratio is acceptable in the frequency band. In recent years, Several attenuation relationships have been developed for different tectonic regions of Iran (e.g Motazedian,2006; Zafarani et al, 2008; Mahood et al, 2009; Hassani et al, 2011) among them Zafarani et al. (2008) attenuation relation resulted in best fitting to our spectra in which the Quality Factor have a frequency dependency of the form:

$$Q_s(f)=291f^{0.6} \tag{6}$$

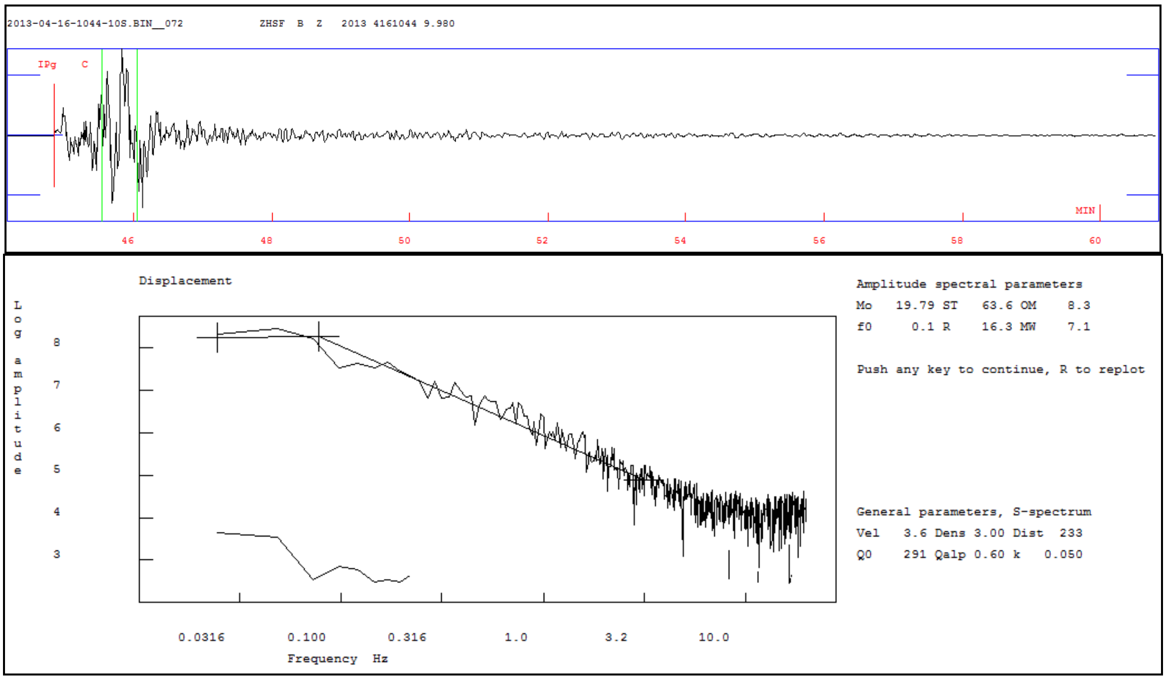
Thus, the spectra were corrected for attenuation using above relation and value of 0.05 considered for near surface attenuation, κ. After correction, Brune's point source model were fitted automatically to the spectra through a grid search procedure (Havskov and Ottemoller , 2008) and the best fitting corner frequency and spectral level were found. Obtained source parameters include seismic moment (M_0), moment magnitude (M_w), source radius (a), corner frequency (f_0) and stress drop (Δσ) that are presented in Table 1 for all 16 stations for p wave using vertical components. Averages of parameters are also shown. The same procedure is performed for S wave spectra of horizontal components and the resultant parameters are shown in Table 2. Fig. 3 shows the procedure of finding source parameters using ZHSF station located 233 kilometers away from earthquake epicenter.

Table1. List of source parameters: logarithm of seismic moment (M_o), moment magnitude (M_W), stress drop (Δσ), corner frequency (f_0) and radius (a) determined using P wave spectra.

Station code	M_0 (N m)	M_w	Δσ (bar)	f_0 (Hz)	a (km)
AHRM	19.49	6.9	12.4	0.1	22.3
ASAO	19.80	7.1	232	0.1	10
BJRD	18.94	6.6	5.4	0.1	19.3
BSRN	19.47	6.9	18.1	0.1	19.3
GHVR	19.81	7.2	128.7	0.1	13
KHMZ	19.52	7.0	198.6	0.1	9.0
KRBR	19.28	6.8	225.1	0.2	7.2
MRVT	19.84	7.2	321	0.1	9.8
SHGR	19.50	6.9	139.4	0.1	10
SHRO	19.30	6.8	131.6	0.1	8.8
SHRT	19.82	7.2	30.6	0.1	21.1
TABS	19.57	7	64.2	0.1	13.7
THKV	18.95	6.6	64.1	0.1	10
YZKH	19.49	6.9	104.5	0.1	11.0
ZHSF	19.45	6.9	93.8	0.1	7.7
ZNJK	19.80	7.1	294.5	0.1	7.1
Average	19.52	7.0	131.0	0.1	12.4

Table 2. List of source parameters: logarithm of seismic moment (M_o), moment magnitude (M_W), stress drop (Δσ), corner frequency (f_0) and radius (a) determined using S wave spectra.

Station code	M_0 (N m)	M_w	Δσ (bar)	f_0 (Hz)	a (km)
AHRM	19.8	7.1	114.8	0.1	13.4
ASAO	20.27	7.5	83	0.1	21.5
BJRD	18.88	6.5	18.1	0.1	30.4
BSRN	19.52	7.6	140.8	0.1	20
GHVR	20.37	7.2	95.5	0.1	15.8
KHMZ	20.81	7.8	193	0.1	24.4
KRBR	19.77	7.1	322	0.1	9.3
MRVT	20.41	7.6	256.9	0.1	16.4
SHGR	20.33	7.5	347.8	0.1	13.9
SHRO	20.5	7.6	124	0.1	22.3
SHRT	19.87	7.2	104.4	0.1	14.7
TABS	20.31	7.5	95.9	0.1	21.1
THKV	19.72	7.1	114.3	0.1	12.7
YZKH	20.52	7.6	266	0.1	17.6
Average	20.05	7.3	149.4	0.1	18.2



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2013-04-16-1044-10S.BIN__072          ZHSF  B  Z   2013 4161044 9.980
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Amplitude spectral parameters
Mo   19.79 ST   63.6 OM    8.3
f0     0.1 R    16.3 MW    7.1

Push any key to continue, R to replot

General parameters, S-spectrum
Vel   3.6 Dens 3.00 Dist  233
Q0    291 Qalp 0.60 k   0.050
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Figure 3. An example of seismic displacement spectra of S wave at ZHSF station. On top is shown the seismogram with the time window used for spectral analysis. The spectrum is corrected for attenuation Q = $291f^{0.6}$ and near surface attenuation κ= 0.05. The epicentral distance is 233 km.

CONCLUSIONS

In this study we determined source parameters of Saravan earthquake include seismic moment, corner frequency, source radius and stress drop using displacement spectra of P and S waves observed at 16 stations of INSN. The spectra of the records were corrected for attenuation then source parameters retrieved by fitting a Brune's point source model.

There are a few studies of source parameters of earthquakes in the Iranian plateau. Hassani et al. (2011) analyzed 190 three-component records corresponded to 40 earthquakes that were recorded at 42 stations with the magnitudes M3.5–M7.3 in the East-Central Iran. The Brune stress drop estimates for individual earthquakes range from about 12 to 350 bars and the average value was around 49 bars. Zafarani and Hassani (2013) used 148 three-component records of 35 earthquakes with the magnitudes M4.2 to M6.2 in the zagros region. The Brune stress drop estimates range from about 140 to 350 bars and the average value is around 66 bars.

The average stress drops obtained here for P and S waves of Saravan earthquake are 131 and 149 bars respectively, which is in the range of individual earthquake stress drops obtained in other studies but is larger than median stress drop values estimated from previous studies for different tectonic regions of Iran (Hassani et al, 2011; Zafarani and Hassani , 2013). However as Boore et al. (2010) discussed, the stress parameter and the attenuation model are closely linked together; the value of the stress parameter by itself cannot be meaningfully compared with other stress parameters determined using different attenuation relations. In addition, various studies have shown that tectonic setting affects the stress drop estimates (Kanamori and Anderson, 1975; Allmann and Shearer, 2009) hence differences in tectonic settings should be taken in consideration when stress drops obtained from different regions and studies compared with each other.

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