Journal of Asian Earth Sciences 79 (2014) 432–440

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

journal homepage: www.elsevier.com/locate/jseaes

# An appraisal of aftershocks behavior for large earthquakes in Persia

Majid Nemati *

*Geology Department of Science Faculty and Earthquake Research Center of Shahid Bahonar University of Kerman, Pajouhesh Sq., Kerman, Iran*

ARTICLE INFO

*Article history:*
Received 29 March 2013
Received in revised form 2 October 2013
Accepted 4 October 2013
Available online 22 October 2013

*Keywords:*
Aftershock
Sequence
Persia
Earthquake
ISC
IGUT
Magnitude

ABSTRACT

This study focuses on the distribution of aftershocks in both location and magnitude for recent earthquakes in Iran. 43 Earthquakes are investigated, using data from the global International Seismological Center (ISC) seismic catalogue and from the regional earthquake catalogue of the Institute of Geophysics, University of Tehran (IGUT) between 1961–2006 and 2006–2012 respectively. We only consider the earthquakes with magnitude greater than 5.0. The majority of these events are intracontinental, occurring over four seismotectonic provinces across Iran. Processing aftershock sequences reported by both catalogues with cut-off magnitude of 2.5 and a sequence duration of 70 days, leads us to define a spatial horizontal area ($A$) occupied with the aftershocks as a function of mainshock magnitude ($M$) for Persian earthquakes: ISC: $\mathrm{Log}_{10}(A) = 0.45M_S + 0.23$; IGUT: $\mathrm{Log}_{10}(A) = 0.25M_N + 1.7$.

Also we found a range for the difference between the magnitudes of the strongest aftershock and of the mainshock in each sequence, which varies from ~0.9 (ISC) to ~1.27 (IGUT). Finally, the spacial distribution of the aftershocks corresponds reasonably well to the causative fault planes of earthquakes.



## 1. Introduction

The physics of the earthquake process, which is based on stick–slip motion on a fault plane, concludes a specific seismic energy is released with each individual slip event. However, in reality nearly all of the large seismic events are followed by numerous small to moderate earthquakes, known as aftershocks. In an aftershock sequence, the magnitude of the largest aftershock is typically assumed to be about one magnitude smaller than of the mainshock (Lay and Wallace, 1995). Nevertheless in a typical aftershock sequence, the total seismic energy released by the aftershocks is actually ~10 times smaller than of the mainshock (Lay and Wallace, 1995). Also the co-seismic fault geometry strongly controls the aftershock spatial elongation. Therefore the area of aftershocks dispersal is very important. Aftershock distribution area, A, has been shown to vary as a function of mainshock magnitude, M. We could point to two pioneer works; Utsu and Seki (1954) and Christophersen and Smith (2000). They calibrated equations using global seismological catalogues (e.g. ISC):

$$\mathrm{Log}_{10}(A) = (1.02 \pm 0.08)M - (4.01 \pm 0.57) \text{ (Utsu and Seki, 1954)} \quad (1)$$

$$\mathrm{Log}_{10}(A) = M - (3.34 \pm 0.03) \text{ (Christophersen and Smith, 2000)} \quad (2)$$

Eq. (1) was derived using 39 Japanese earthquakes with $M > 5.0$, while Eq. (2) was derived using 120 earthquakes globally, with $M > 6.0$ recorded over 32 years. Utsu and Seki (1954) relation yields value of $A$ almost 3.3 times greater than Christophersen and Smith (2000) model. The area of an aftershock sequence is defined by an ellipse which fits to more than 90% of data by at least three near boundary aftershocks.

The faulted area $\mathbb{A}$ (km$^2$), is proportioned to mainshock magnitude and can be calculated using empirical relationships developed by researchers (e.g. Papazachos et al., 2004; $\mathrm{Log}_{10}(\mathbb{A}) = 0.82M - 2.79$, $6.0 < M < 8.0$, for strike–slip and $\mathrm{Log}_{10}(\mathbb{A}) = 0.78M - 2.56$, $6.0 < M < 7.5$, for dip–slip faults). The area mentioned in this formula is different with of this topic and is ruptured area excluding the area extended by the aftershocks.

Using two separate databases, we determine new relationships between the aftershock distribution area, A, and mainshock magnitude, $M$, for recent earthquakes in Iran. From the IGUT catalogue, 22 earthquakes were included from 2006 to 2012 with cut-off magnitude 5.0+ for the mainshocks. For earthquakes prior to 2006, we utilize the ISC catalogue, because IGUT catalogue is not included the data in mentioned time range. Before this time 21 earthquakes with the magnitude greater than 6.0 extracted from ISC catalogue between 1961 and 2005. Both catalogues were searched with a constant time range. We did not search in catalogues for specific space criteria; therefore the spatial areas occupied by aftershocks within 2 months after the mainshock were completely searched. Consequently they may contain a few micro-earthquakes from background seismicity. The number of the aftershocks included in the model for each sequence varies

* Tel.: +98 3413222035.
*E-mail address:* majid_1974@uk.ac.ir

1367-9120/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jseaes.2013.10.015

between 2 for Torbat-e Heydarieh earthquake (2010/10/30) and 1298 for Ahar-Varzaghan earthquake (2012/8/11).

The calculated relationships using the ISC and IGUT databases will differ slightly. They may vary between strike–slip and thrust earthquakes, and between the seismotectonic provinces. The intracontinental and intercontinental regions experience different earthquakes with different stress drops and therefore different aftershock behaviors. Because the previous works did not separate the earthquakes based on their regional location, we encouraged investigating intracontinental Iranian earthquakes from 1961 to 2012 separately.

## 2. Database

Moment magnitude reflects the overall energy released from the earthquake source and provides the most robust estimate of energy released across a wide range of scales. Estimates of moment magnitude can be determined using body waveform inversion, the moment tensor solution, or derived from spectral contents of the waveforms recorded by broad-band seismometers. In early years (1961–1977) the ISC catalogue may contain events with underestimated magnitudes. From 1977 onwards, moment magnitude for earthquakes have globally been reported by Catalogues (e.g. Harvard Catalogue). The $m_b$ and $M_S$ scales are calculated using amplitude picking of body waves and surface waves of the earthquakes recorded in their frequency ranges, respectively. They cannot represent all of source process energy, because the frequencies at which the $m_b$ and $M_S$ are determined do not record the whole rupture process. Although the ISC catalogue reports $m_b$ and $M_S$ scales for magnitude of the located earthquakes, the $M_W$ scale which adapted from documented earthquakes occurred in Persia prior to 2006 (Appendix) were used. After 2006 we used $M_N$ scale (Nuttli, 1973) which is calculated in IGUT for the events.

**Table 1**
Earthquakes characteristics used in this study adapted from the ISC catalogue. The parameters (*a* and *b*) are length of great and small axes (in inches) of the fitted ellipse to each sequence respectively.

| No | Earthquake | Date | Long. (°N) | Lat. (°E) | Depth (km) | $M_S$ | N. Aft. | *a* (in) | *b* (in) | Scale (in/100 km) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Lar | 11/6/1961 | 54.51 | 27.93 | 2.0 | 6.4 | 39 | 0.5 | 0.26 | 0.93 |
| 2 | Buyin-Zahra | 1/9/1962 | 49.88 | 35.58 | 29.0 | 7.5 | 10 | 0.79 | 0.4 | 1.2 |
| 3 | Dasht-e Bayaz | 31/08/1968 | 59.5 | 34.9 | 33.0 | 7.3 | 22 | – | – | – |
| 4 | Qir-o Karzin | 10/4/1972 | 52.785 | 28.395 | 10.6 | 6.9 | 39 | 0.55 | 0.24 | 0.93 |
| 5 | Dasht-e Bayaz | 27/10/1979 | 59.806 | 34.029 | 3.0 | 7.1 | 50 | 1.95 | 0.38 | 1.08 |
| 6 | Khourgu | 21/03/1977 | 56.379 | 27.588 | 23.8 | 6.2 | 76 | 0.85 | 0.36 | 0.93 |
| 7 | Tabas-e Golshan | 16/09/1978 | 57.437 | 33.369 | 34.1 | 7.4 | 57 | 1 | 0.67 | 1.08 |
| 8 | Sirch-Golbaf | 28/07/1981 | 57.770 | 29.988 | 11.1 | 7.3 | 40 | 0.9 | 0.52 | 1.08 |
| 9 | Ali Abad-e Gorgan | 20/10/1985 | 54.810 | 36.750 | 15.0 | 6 | – | – | – | – |
| 10 | Roudbar-e Tarom | 20/06/1990 | 49.346 | 36.989 | 18.5 | 7.7 | 70 | 1.75 | 1.1 | 1.2 |
| 11 | Sefidabeh | 23/02/1994 | 60.570 | 30.806 | 6.0 | 6.6 | 15 | 0.55 | 0.23 | 1.08 |
| 12 | Bojnourd | 4/2/1997 | 57.289 | 37.739 | 10.0 | 6.4 | 16 | 0.92 | 0.52 | 1.57 |
| 13 | Ardebil | 28/02/1997 | 48.041 | 38.088 | 39.2 | 6.4 | 10 | 1.08 | 0.56 | 2.25 |
| 14 | Zirkuh-e Ghaen | 10/5/1997 | 59.823 | 33.878 | 6.7 | 7 | 80 | 1.8 | 0.37 | 1.08 |
| 15 | Fandogha | 14/03/1998 | 57.612 | 30.161 | 43.5 | 6.7 | 22 | 1 | 0.47 | 1.08 |
| 16 | Central Zagros | 6/5/1999 | 51.917 | 29.534 | 17.2 | 6.1 | | | | |
| 17 | Avaj | 22/06/2002 | 49.022 | 35.589 | 10.0 | 6.7 | 12 | 0.55 | 0.32 | 1.2 |
| 18 | Bam | 26/12/2003 | 58.304 | 28.965 | 15.0 | 6.7 | 32 | 0.65 | 0.33 | 1.08 |
| 19 | Baladeh-e Kojour | 28/05/2004 | 51.587 | 36.321 | 17.0 | 6.4 | – | – | – | – |
| 20 | Dahouieh-e Zarand | 22/02/2005 | 56.807 | 30.770 | 13.0 | 6.3 | 103 | 0.55 | 0.37 | 1.08 |
| 21 | Qeshm | 27/11/2005 | 55.827 | 26.748 | 10.0 | 6 | 71 | – | – | – |

**Table 2**
Earthquakes characteristics used in this study adapted from the IGUT catalogue. The parameters (*a* and *b*) are length of great and small axes (in inches) of the fitted ellipse to each sequence respectively.

| No | Earthquake | Date | Long. (°N) | Lat .(°E) | Depth (km) | $M_N$ | N. Aft. | *a* (in) | *b* (in) | Scale (in/100 km) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Haji Abad | 28/02/2006 | 56.462 | 28.205 | 18.0 | 5.8 | 19 | 0.50 | 0.23 | 0.930 |
| 2 | bandar-e Abbas | 25/03/2006 | 55.440 | 27.451 | 21.7 | 6.0 | 56 | 0.63 | 0.59 | 0.930 |
| 3 | Boroujerd | 31/03/2006 | 48.864 | 33.483 | 18.0 | 5.9 | 219 | 0.65 | 0.45 | 0.930 |
| 4 | Qeshm | 28/06/2006 | 55.747 | 26.665 | 16.7 | 5.5 | 17 | 0.45 | 0.18 | 0.930 |
| 5 | Qom | 18/06/2007 | 50.866 | 34.498 | 14.0 | 5.9 | 121 | 0.56 | 0.30 | 1.200 |
| 6 | Shoush | 27/08/2008 | 47.325 | 32.344 | 20.5 | 5.7 | 185 | 0.60 | 0.36 | 0.930 |
| 7 | Qeshm | 10/9/2008 | 55.829 | 27.002 | 9.5 | 6.0 | 42 | 0.55 | 0.23 | 0.930 |
| 8 | Qeshm | 7/12/2008 | 55.909 | 26.884 | 11.1 | 5.6 | 27 | 0.60 | 0.23 | 0.930 |
| 9 | Koodian-e Bastak | 20/07/2010 | 53.899 | 27.040 | 9.5 | 5.8 | 46 | 0.45 | 0.33 | 0.930 |
| 10 | Torbat-e Heydarieh | 30/07/2010 | 59.252 | 35.222 | 7.1 | 5.7 | 2 | 0.45 | 0.30 | 1.080 |
| 11 | Negar-e Kerman | 31/07/2010 | 56.812 | 29.703 | 4.0 | 5.8 | 35 | 0.60 | 0.20 | 1.080 |
| 12 | Touchahi-e Damghan | 27/08/2010 | 54.466 | 35.488 | 6.7 | 5.9 | 120 | 0.95 | 0.41 | 1.200 |
| 13 | Konar Takhteh-e Kazeroun | 27/09/2010 | 51.618 | 29.693 | 26.1 | 6.1 | 64 | 0.70 | 0.34 | 0.930 |
| 14 | South Firouz Abad | 26/11/2010 | 52.473 | 28.040 | 12.0 | 5.4 | 105 | 0.51 | 0.35 | 0.930 |
| 15 | Rigan | 20/12/2010 | 59.153 | 28.443 | 13.3 | 6.5 | 124 | 0.75 | 0.55 | 1.080 |
| 16 | Rigan | 27/01/2011 | 58.948 | 28.289 | 10.0 | 6.0 | 135 | 0.80 | 0.58 | 1.080 |
| 17 | Kahnooj | 15/06/2011 | 57.766 | 27.784 | 34.0 | 5.3 | 30 | 0.85 | 0.40 | 1.080 |
| 18 | Sirch | 26/06/2011 | 57.630 | 30.206 | 12.9 | 5.0 | 17 | 0.90 | 0.52 | 1.080 |
| 19 | Marzicola-e Mazandaran | 11/1/2012 | 52.781 | 36.329 | 16.3 | 5.0 | 28 | 0.45 | 0.18 | 1.200 |
| # | Neyshabour | 19/01/2012 | 58.835 | 36.288 | 8.3 | 5.5 | 42 | 0.52 | 0.32 | 1.570 |
| 21 | Bostan | 3/5/2012 | 47.605 | 32.738 | 10.0 | 5.5 | 50 | 0.55 | 0.26 | 0.930 |
| # | Ahar-Varzaghan | 11/8/2012 | 46.806 | 38.433 | 9.0 | 6.2 | 1298 | 1.20 | 1.00 | 2.250 |