AFTERSHOCK DECAY RATES IN THE ZAGROS AND PROBABILISTIC SEISMIC AFTERSHOCK HAZARD ANALYSIS OF THE 2013 APRIL 9 SHONBE (BUSHEHR) EARTHQUAKE

Salma OMMI
PhD Student, International Institute of Earthquake Engineering and Seismology (IIEES), Iran, Tehran
s.ommi@iiees.ac.ir.

Hamid ZAFARANI
Associate Professor, International Institute of Earthquake Engineering and Seismology (IIEES), Iran, Tehran
h.zafarani@iiees.ac.ir.

Keywords: Aftershock Rate, Omori's Law, Attenuation Relations, Probabilistic Hazard, Shonbe Earthquake

ABSTRACT

The main goal of this article is to study the Zagros aftershock decay rates. For this propose, the Iranian earthquake catalogue has been collected and homogenized between 2002 to 2014. Eight prominent earthquakes in the Zagros region were selected for aftershock decay rate study. Completeness magnitude and its variation was determined for each event. In order to investigate the behavior of aftershocks in the Zagros seismotectonic province, the Omori law parameters were calculated for selected events. Then, probabilistic aftershock hazard assessment (PAHA) based on aftershock parameters (a, b, P, K) of the 2013 April 9 Shonbe earthquake, has been estimated in temporal duration of 14, 30 and 60 days. In order to evaluate the variation of peak ground acceleration with time in the Zagros region, present attenuation relations and NGA formula has been applied. For calculating the PGA variations with time in 33% probability, we used logic tree for weighing different equation.

INTRODUCTION

Iranian plateau, located in the Alpine-Himalayan belt, has been ruptured by several stem faults. Having concern towards seismicity and the earthquake hazard in such a region is of high significance. Considering the critical point that earthquake phenomenon is divided into three stages, known as: preparation for earthquake (foreshocks), main event, and aftershocks, the design of procedures for identifying and differentiating these stages in the seismic regime can help in better understanding of earthquake phenomenon and consequently can possibly decrease the hazards of earthquake. Working on aftershocks studies can be important from different aspects, the impact that aftershocks have on the destroyed structures which have been damaged in the earthquake from one side, and the disturbance caused in rescue process from another side show the necessity of this study (Hough and Jones, 1997). Among the hazardous aftershocks, we could refer to the M= 5.8 aftershock of the earthquake occurred in Izmir, Turkey (M=7.4), in 1999 which caused 7 dead, aftershock of Hindu kush earthquake (M=6) happened in Afghanistan in 2002, the aftershock (M_N=6.3) of Ahar-Varzaghan earthquake (M_N=6.5) which occurred in Iran 2013. The geographical distribution of aftershocks includes some data and information regarding the geometric expansion of the seismic region, and also it can play a key role in the progress of fault analysis. The mass of aftershocks in one section of fault not only can be completely separate and independent from another section but also it could have a different spatial distribution and decay rate. This difference which is resulted from the stress level difference in each section of fault (Wiemer and Katsumata, 1999) can include some information related to how stress is distributed in seismic region. Moreover, studying aftershocks is considered as a significant effective step towards knowing the physical process of earthquake (Kisslinger, 1996). Aftershocks happen due to the heterogeneity stress in seismic zone caused by the main event occurrence. As the time passes and gets further from the time of the main event, their occurrence reduces and the seismic rate gets closer to the basic rate. Many studies have been carried out to provide a systematic explanation regarding this rate reduction. Dieterich in 1986 was analyzing the effects of slip rate, slip speed, shear stress, and normal stress on fault events rate by equalizing the stress effects on the earthquake rate of one fault in his laboratory. As a result of this, he formulated the seismic rate relation with stress history (Dieterich, 1994). Rundle et al (1996b), believing the fact that clustering is not an accidental process, researched the physical basis of the process of aftershocks production. He emphasizes on the relation between the decay of the cluster rate and the function of seismic region. According to this, the study of the decay of the cluster rate can be one of the factors for seismicity of one seismic region. Furthermore, risk studies resulting from aftershocks need some basic information about the decay rate of aftershocks function in each region (Lolli and Gasperini, 2003).Seismic rate for aftershocks in time (t) follows Omori law revised by Utsu(1961):

$$R(t) = \frac{K}{(C+t)^P} \tag{1}$$

t is the time distance to the main event, K, C, P are the fixed coefficients. The inserted variable C is considered to prevent from the overlapping of the aftershocks and the main event. For variable C, Kagan and Y and Houston (2005) have done a thorough study by calculating this parameter for three huge earthquakes in California and measured the positive and negative effect of these figures. They introduced the prevention from overlapping of aftershocks and main event, lack of complete analysis of seismogram data, the lack of the extended spatio-temporal character of earthquake rupture zone implying failure of the point model of the earthquake source as the reasons for emerge of this parameter. Figure P represents the speed of rate decay in the revised Omori Law, the range of its differences for California has been 0.7 to 1.8 (Kisslinger and Jones, 1991) and related to place has been 0.6 to 1.4 (Wiemer and Katsumata, 1999). Parameter P is considered as one of the most significant factors for measuring the differences of the seismic potential since the study and analysis of its increasing or decreasing differences in relation with time and place demonstrates the heterogeneity rise or reduction of the material. Studying the catalogues of Romani and Japan proves that the growth in the figure b in Gutenberg -Richter trend and figure P of Omori Law show the increase in heterogeneity material and decrease in stress; for Tottori earthquake 2000, these parameters have been calculated for aftershocks, the geographical distribution of these two parameters show its maximum figure in the location of the main event being occurred, the justification of this model can be possible through stress changes and/or crystal structure (Enescu et al., 2011).

CATALOGUE OF EARTHQUAKES

To calculate Omori Law parameters for Iranian plateau, a catalogue has been collected which includes the time duration between the years 2000 to 2013. This data has been provided by the Institute of Geophysics, Tehran University (IGUT) and the International Institute of Earthquake Engineering and Seismology (IIEES).The magnitude reported by IGUT is M_N and the magnitude reported by IIEES after the year 2000 is M_L. In the present study, to homogenize the magnitudes, it has been used from the relations M_N-M_L and M_N-M_W developed by Shahvar and Zare (2013). Finally, the catalogue is homogenized based on the magnitude M_N, and its shared events have been eliminated. Due to the extended development of the seismography channels in Iran in the recent years, the chosen events for calculating Omori Law parameter belong to the years after 2002. The chosen earthquakes for calculating Omori Law parameters have been selected considering having initial correct data regarding magnitude, geographical location, and depth. Moreover, these catalogue selected earthquakes include enough number of registered aftershocks. To study and analyze the chain of accidents, the events of each cluster have been gathered. With the purpose of doing this study and creating this catalogue of earthquakes, the spatial and temporal windows of Gardner and

Knopoff (1974) has been used.

SELECTED EVENTS IN THE ZAGROS SEISMOTECTONIC REGION

The prominent seismic events which was occurred in the Zagros seismotectonic zone and categorized based on M_N more than or equal 5.7 was chosen in this study. These are the events which benefit from the least coverage of seismography channel and have an enough amount of aftershocks for calculating Omori Law parameters. There are 8 earthquakes in table 1 in which the geographical width and length characteristics, depth, time of each event, and magnitude of each event could be seen.

Table 1- the initial data for the selected earthquakes of Iran: **Date** and **Time** events, latitude **Lat**, longitude **Lon**, depth **Dep**, the magnitude of the main event $\mathbf{M_N}$ and the **Location** of the main event*. *The earthquakes whose aftershocks still carry on. ¤ the earthquakes which have less than 0.6 magnitude difference with their biggest aftershocks. †the events whose geographical location and magnitude have been extracted from (IGUT) based on $\mathbf{M_N}$. ‡The events whose geographical location and magnitude have been extracted from (IIEES) based on $\mathbf{M_W}$ and have been converted to $\mathbf{M_N}$ with Shahvar relation $\mathbf{M_N} - \mathbf{M_W}$.

No	Date	Time	Lon	Lat	Dep	M_N	Location
1	2005-11-27‡	22:06.9	55.89	26.88	10	5.9	Qheshm1(PersionGulf)
2	2006-02-28‡	07:31:09	56.462	28.205	18	5.8	Tiab(Faryab)
3	2006-03-25¤†	07:29:00	55.44	27.451	21.7	6	Fin(Bandar Abbas)
4	2006-03-31†	01:17:04	48.864	33.483	18	5.9	Silakhor
5	2008-08-27†	21:52:41	47.325	32.344	20.5	5.7	Moosiyan(Iran-Iraq)
6	2008-09-10¤†	11:00:35	55.829	27.002	9.5	6	Qheshm2
7	2010-09-27¤†	22:18.8	51.618	29.693	26.1	6.1	Kazeroon
8	2013-04-09*†	11:52:58	51.568	28.467	20	6.3	Bushehr

ZAGROS SEISMOTECTONIC PROVINCE

Seismotectonic province is an area under present geodynamic regimes which has a similar strike-slip and equal seismic model (Jackson and MacKenzi, 1988), with concept of which Iran has been divided into five tectonic provinces by Mirzaei et al.,1998: 1) Alborz- Azerbaijan, 2) Kopeh dagh, 3) Zagros, 4) Makran, 5) Centeral Iran.

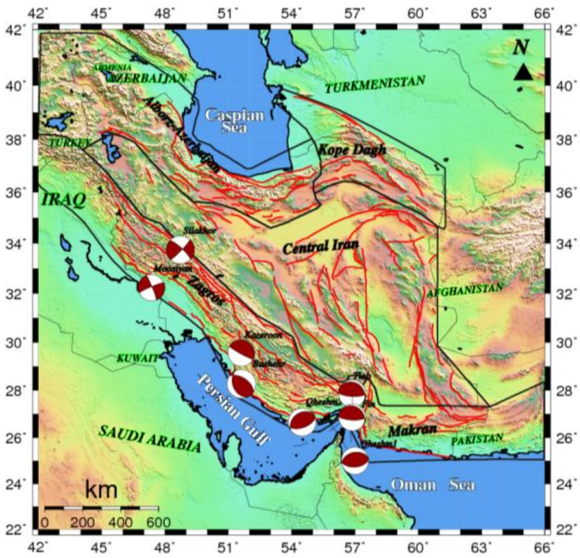


Figure 1. focal mechanism of selected main shocks (extracted from Harvard University site (GCMT)), the red line represents the location of important faults in Iran's plateau (map of major active faults of Iran (Hessami, et al., 2006 has been used). The boundary of Iranian seismotectonic provinces have been illustrated and named by black based on Mirzaei (Mirzaei et al, 1998).

The pleated expulsive belt of Zagros is a part of Alp-Himalayan orogenic belt and one of the youngest and most seismically active continental areas on the earth (Ni and Barazangi, 1986). In the Zagros, probably 10 per cent or less of the upper-crustal deformation is seismic and the rest must be accommodated by creep. Dominantly aseismic deformation in the Zagros is seems to be related to the great thickness of sediments, partly decoupled from the basement by salt, in both places. This may lead to elevated basement temperatures and inhibit upward fault propagation, thus restricting the size of seismogenic fault planes (and hence seismic moment) and causing the sedimentary cover to deform independently from the basement, partly by folding (Jackson and McKenzi, 1988).

CALCULATION OF SEISMIC PARAMETERS FOR AFTERSHOCKS

To determine the Omori law variables, the best way is to find them with maximizing likelihood function (Ogata, 1983). The likelihood function for the aftershock sequence can be written as:

$$L = \left\{\prod_i \lambda(t_i)\right\} \exp\left\{-\int_s^T \lambda(t)dt\right\} \qquad (2)$$

where λ is aftershock rate, t_i is occurrence time of events and [T, S] is the observation period.

With the purpose of finding the coefficients, the log-likelihood is given by:

$$\text{Ln}\,L(K,C,P) = \sum_{i=1}^{N} \lambda(t_i) - \int_s^T \lambda(t)dt = N \ln K - P\sum_{i=1}^{N} \ln(t_i + C) - KA(C,P) \qquad (3)$$

with

$$A(C,P) = \begin{cases} \ln(T+C) - \ln(S+C); & P = 1 \\ \dfrac{(T+C)^{1-P}(S+C)^{1-P}}{1-P}; & P \neq 1 \end{cases} \qquad (4)$$

Therefore, as the likelihood function is maximized, the parameters K, C and P could be determined.
The b-value is also calculated using the maximum likelihood method (Aki, 1965):

$$b = \frac{\log(e)}{\left(M_{mean} - \left(M_{min} - \frac{\Delta M_{bin}}{2}\right)\right)} \qquad (5)$$

In this formula, M_{mean} is the mean magnitude and M_{min} is the minimum magnitude, ΔM_{bin} is the binning width of catalogue. Parameter A that has some information regarding the seismicity rate of the region could be calculated based on b and K with the following formula which was found and developed by Gasperini and Lolli (2006). In this formula, M_{max} is the magnitude of the main event.

$$A = \log(K) - b(M_{max} - M_{min}) \qquad (6)$$

With the help of the above-mentioned method, the calculation of Omori Law parameters for the selected earthquakes of Iran have been estimated with the calculation of the occurrence time of the registered events (Table 3) in order to study the rate changes and the decay rate of the aftershocks.

PROBABILISTIC AFTERSHOCK HAZARD ASSESSMENT

Wiemer (2000) suggested the so-called probabilistic aftershock hazard assessment (PAHA), based on the classical probabilistic seismic hazard approach (PSHA, Cornell 1968). In aftershock hazard maps, much shorter periods are interested, however, generally hazard maps calculated in long periods. Probability and time period for forecasting ground motion parameter are dependent to quality and quantity aftershocks catalogue. Aftershock hazard maps are time-dependent. In PAHA maps, time dependency is integrated through the modified Omori law. The computation of hazard maps requires the definition of source zones. Source zones has been obtained rectangular zones based on number of aftershock. (Wiemer et al., 2002). The rate aftershocks with magnitude more than M_C at given time interval (t) after a main shock of magnitude M_m can be determined by the Reasenberg and Jones (1989) model:

$$\lambda(t, M_C) = \frac{10^{a+b(M_m - M_C)}}{(t+C)^P} \quad (7)$$

For calculating aftershock hazard map of Bushehr-Shonbe earthquake (2013.04.09, M_N=6.3), sequence less than magnitude completeness (M_C=2.8) was removed and set largest aftershock to be 0.5 unites smaller than the main shock (Rosenberg and Jones, 1989). In this study, hazard aftershock map was calculated for second 14 days, 30 days, and 60 days after main shock, for 0.33% constant value of probability at varying times after the main shock. The seismicity parameters (a,b,P) extracted for each source zones of the three periods (14 days, 30 days and 60 days after earthquake). From the above method, rate of aftershock was calculated. For each zone, Seismicity parameters depend on the different time intervals of the aftershocks. Seismicity parameters in each period of time could be computed With Maximum Likelihood Estimation method (MLE) (Aki, 1965) (table4).

Table 3. **Date** shows the occurrence time of the event, **M_N** is the magnitude of the main event, **Duration** is the time period in which the aftershocks have happened, **N** is the number of aftershocks in spatial and temporal windows (Gardner- Knopoff), **N>C** shows the number of the aftershocks which have a bigger magnitude than the magnitude of completeness **Mc**, aftershock parameters **P**, **K**, and **C** with the calculated error (**Err**), seismic parameters A and b have been estimated for each event.

Date	M_N	Duration	N	N>C	Mc	K	Err	P	Err	C	Err	A	b-value
2005-11-27	5.9	372	68	52	3.1	10	0	1.14	0.07	0.507	0.31	-1.43	0.9
2006-02-28	5.8	434	62	38	3.1	10	0.81	1.2	0.06	2.1	1.2	-0.81	0.67
2006-03-25	6	486	82	78	2.7	10	1.12	0.99	0.03	0.106	0.17	-1.20	0.71
2006-03-31	5.9	414	306	150	2.7	18.6	6.3	0.97	0.07	0.183	0.18	-1.46	0.88
2008-08-27	5.7	351	215	148	2.6	11.5	13.2	0.85	0.17	0.01	0.24	-1.79	0.95
2008-09-10	6	457	130	87	3.1	10	6.07	0.94	0.04	0.18	0.41	-1.07	0.74
2010-09-27	6.1	506	267	102	2.4	10	0.07	0.94	0.02	5	0.4	-1.84	0.79
2013-04-09	6.3	479	272	215	2.8	43.5	19.54	1.16	0.13	0.47	0.25	-0.78	0.71

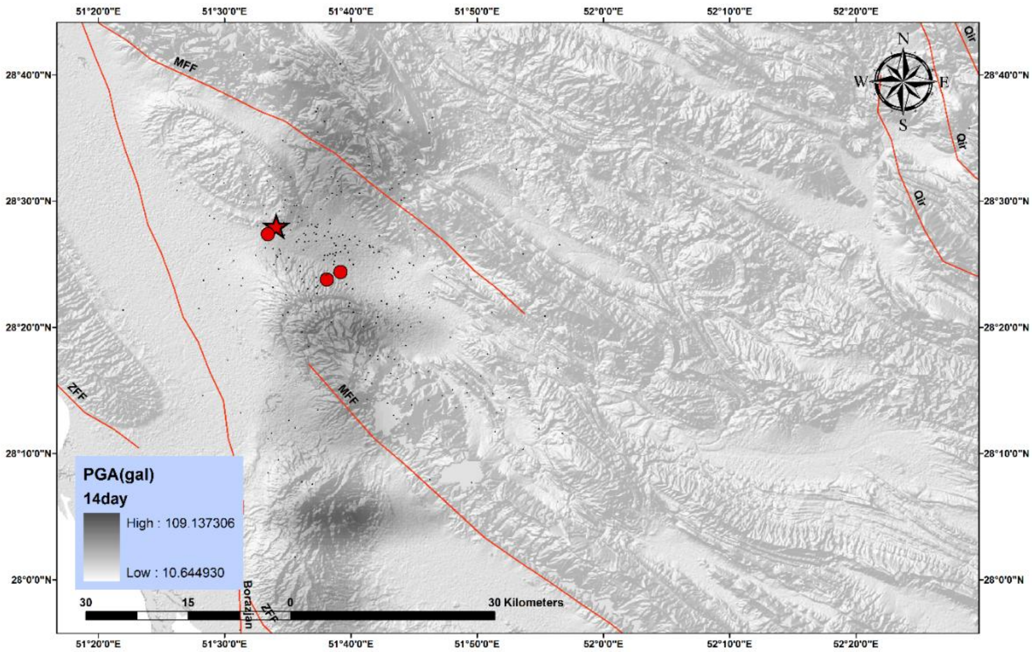
average	15.45	5.88875	1.02375	0.07375	1.0695	0.395
median	10	3.595	0.98	0.065	0.3265	0.28
std-dev	11.71	7.14	0.12	0.05	1.72	0.33

Table4. Seismicity parameters for three time intervals of Bushehr-Shonbe aftershocks.

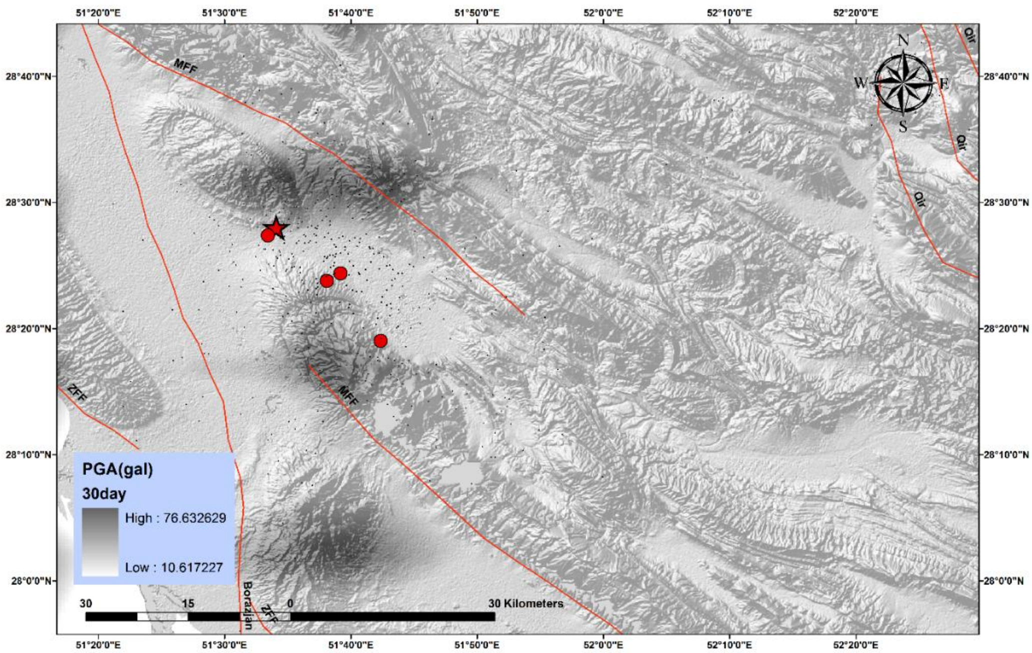
Bushehr-Shonbe	P	C	K	b
14 Day	1.8±0.35	1.17±0.58	292±59.9	0.68+0.04
30Day	1.04±0.11	0.38±0.1	83.4±23.34	0.63+0.03
60 Day	1.05±0.07	0.26±0.11	73.1±17.04	0.64+0.03

To compute the PAHA maps, 7 attenuation relation have been utilized: the NGA models of Abrahamson and Silva(2008), Akkar and Bommer (2010), Boore and Atkinson (2008), Campbell and Bozorgnia (2008) and Chiou and Youngs (2008) and the regional models: Ghasemi et al. (2009a) and Zafarani et al.(2012) . Based on the LLH parameters extracted from study of Mousavi et al. (2012) attenuation relations are weighed and then peak ground acceleration has been estimated for second 14 days, 30 days and 60 days after the main shock(Figure 2).
Comparison the second 14-days forecasts with 30 and 60 days after the main shock for the same probability of exceedance (33%) prove the aftershock hazard decreases with time.

(A)


51°20'0"E
51°30'0"E
51°40'0"E
51°50'0"E
52°0'0"E
52°10'0"E
52°20'0"E
28°40'0"N
28°30'0"N
28°20'0"N
28°10'0"N
28°0'0"N
MFF
ZFF
Qir
Borazjan
N
S
W
E
PGA(gal)
14day
High : 109.137306
Low : 10.644930
30
15
0
30 Kilometers

(B)


51°20'0"E
51°30'0"E
51°40'0"E
51°50'0"E
52°0'0"E
52°10'0"E
52°20'0"E
28°40'0"N
28°30'0"N
28°20'0"N
28°10'0"N
28°0'0"N
MFF
ZFF
Qir
Borazjan
N
S
W
E
PGA(gal)
30day
High : 76.632629
Low : 10.617227
30
15
0
30 Kilometers

(C)

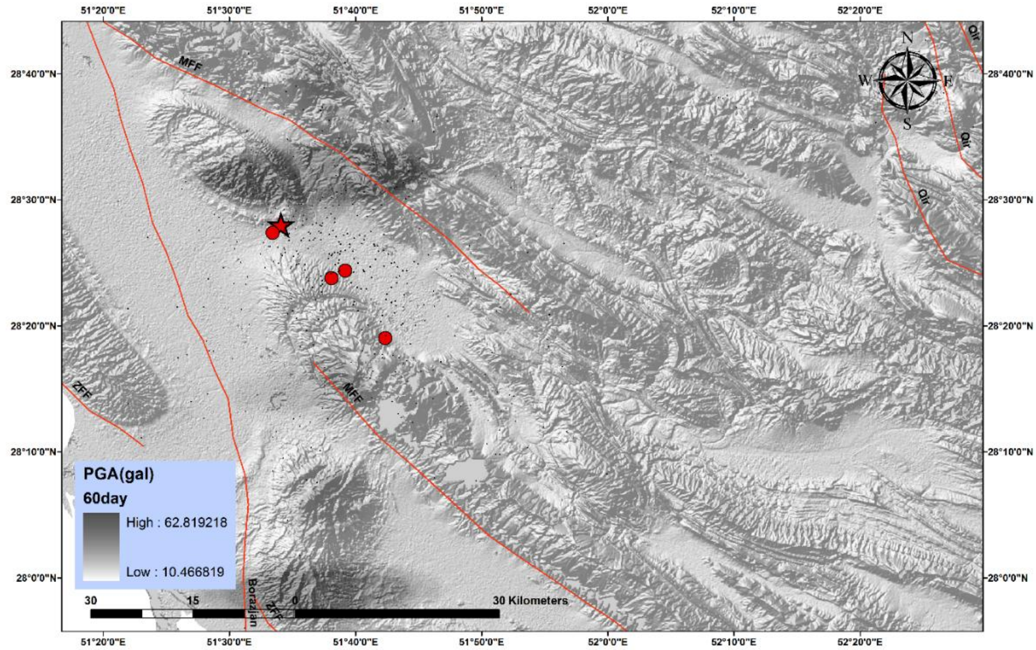


Figure 2. Probabilistic aftershock hazard maps for the same probability of exceedance (33%) in different time intervals after the main shock. Dark blue color indicates the forecasted peak ground acceleration (cm/s/s) for (A) second 14 days, (B) second 30 days and (C) second 60 days after the main shock, a star marks the hypocenter of main events. Larger aftershocks are marked with a red circle ($M_N \geq 5$).

CONCLUSIONS

The calculation of the seismicity parameters and the Omori law parameters in spatial and temporal windows of the aftershock occurrence can improve our knowledge regarding the seismic potential and seismic behavior of different regions. Concerning the aftershock hazard analysis as well as risk analysis studies, these investigations are also important. In this research, the aftershock decay rate has been estimated for some carefully selected earthquakes of Zagros seismotectonic province ($M \geq 5.7$) with the use of the modified Omori formula (Utsu, 1961). Probabilistic aftershock hazard analysis for Bushehr-Shonbe earthquake with a probability of exceedance (33%) shows the maximum acceleration (PGA 110cm/s/s) in the second 14 days after the main event. Hazard maps predicted the maximum acceleration in second 30 days less than 0.1g (PGA 76cm/s/s). Since, the region with noticeable acceleration are reduced, aftershock hazard analysis prove the hazard probability reduction 60 days after main event.

REFERENCE

Abrahamson N, Atkinson G, Boore D, Bozorgnia Y, Campbell K, Chiou B, Idriss IM, Silva W and Youngs R (2008) "Comparisons of the NGA ground-motion relations," Earthquake Spectra 24(1), 45–66

Akkar S and Bommer JJ (2010) "Empirical equations for the prediction of PGA, PGV and spectral accelerations in Europe, the Mediterranean Region and the Middle East," Seismological Research Letters 81(2), 195–206

Akaike H (1974) A new look at the statistical model identification IEEE Trans Autom Control 19, 716–723
Aki, k (1965) Maximum likelihood estimate of b in the formula log N =a –bM and its conference limits BullEarthquke ReInsTokyo Univ, 43, 237-239

Campbell K and Bozorgnia Y (2008) NGA ground motion model for the geometric mean horizontal component of PGA, PGV, PGD and 5%-damped linear elastic response spectra for periods ranging from 001 to 10 s Earthq Spectra 24:139–171

Chiou BS and Youngs RR (2008) “An NGA model for the average horizontal component of peak ground motion and response spectra,” Earthquake Spectra 24(1), 173–215

Cornell, C A (1968) Engineering seismic risk analysis Bull Seismol Soc Am 58:1583–1606

Dieterich JH (1986) A model for nucleation of earthquake slip, in earthquake source mechanics, Geophys Monogr vol37, 37-4

Dieterich, JH (1994) A constitutive law for rate earthquake production and its application to earthquake clustering Journal of Geophysical Research, 99, 2601-2618

Enescu B and Ito, K (2002)Spatial analysis of the frequency-magnitude distribution and decay rate of aftershock activity of the 2000 Western Tottori earthquake *Earth Planets Space*, **54**, 847–859

Enescu, B, Enescu, D and Ito, K (2011) Values of b and p: Their Variations and Relation to Physical Processes for Earthquakes in JAPAN and ROMANIA Rom Journ Phys, Vol 56, Nos 3–4, 590–608

Gardner JK and Knopoff L (1974) Is the sequence of earthquakes southern California, with aftershocks removed Poissonian? Bulletin of the seismological society of America, 64, PP1363-1367

Gasperini P and Lolli B (2006) Correlation between the parameters of the aftershock rate equation: implications for the forecasting of future sequences, Phys Earth Planet Inter156, PP 41-58

Ghasemi H, Zare M, Fukushima Y and Koketsu K (2009) “An empirical spectral ground-motion model for Iran,” Journal of Seismology 13, 499–515

Hessami K and Jamali F (2006) Explanatory Notes to the Map of Major Active Faults of Iran, JSEE: Spring 2006, Vol 8, No 1

Hough S E and Jones LM (1997) Aftershocks: Are they earthquakes or afterthoughts? Eos, vol78, No, 45, PP505-508

Jackson JA and McKenzi DP (1988) The relation between plate motions and seismic moment tensors, and the rates of active deformation in the Mediterranean and the Middle East, Geophys J R astr Soc, 93, 45-73

Jackson, J A and Mc Kenzi, DP (1984) Active tectonics of the Alpine-Himalayan belt between Western Turkey and Pakistan, Geophys J R astr Soc, 77, 185-264

Jackson J, Haines J and Holt W (1995) the accommodation of Arabia-Eurasia plate convergence in Iran, JGeophys Res, 100, 15205-15219

Kagan, Y and Jackson, D (1991) Seismic Gap Hypothesis: Ten years after Journal of Geophysical Research, 96(B13), PP 21419–21431

Kagan Y and Houston H (2005) Relation Between main shock rupture process and Omori’s low for aftershock moment release rate Journal of Geophysical Research, Int, 1039-1048

Kisslinger C and Jones LM (1991) Properties of aftershock in southern California J Geophys Res, 96, 11,947-956
Kisslinger, C (1996) Aftershocks and fault-zone properties, Advance in Geophysics, 38, Academic press, San Digo, 1-36

Lolli B and Gasperini P (2003) Aftershocks hazard in Italy Part I: Estimation of time-magnitude distribution model parameters and computation of probabilities of occurrence Journal of Seismology **7:** 235–257, 2003

Mousavi M, Ansari A, Zafarani H and Azarbakht A (2012) Selection of Ground Motion Prediction Models for Seismic Hazard Analysis in the Zagros Region, Iran Journal of Earthquake Engineering 16:1184–1207

Mirzaei N, Gao M and Chen YT (1998) Seismic source regionalization for seismic zoning of Iran: major seismotectonic provinces J Earthquake prediction Research, 7, 465-495

Ni J and Barazangi M (1986) Seismotectonics of the Zagros continental collision zone and a comparison with the Himalayas, J Geophys Res, 91, 8205-8218

Ogata Y (1983) Estimation of the parameters in the modified Omori formula for aftershock frequencies by the maximum likelihood procedure J, PhysEarth, 31,115-124

Ogata Y (1988) Statistical models for earthquake occurrences and residual analysisoc for point processes J Am Stat Assoc Applic 83 (401), 9–27

Ogata Y and Katsura, K (1993) Analysis of temporal and spatial heterogeneity of magnitude frequency distribution inferred from earthquake catalogs, Geophys J Int 113, 727–738

Reasenberg PA and Jones, L M (1989) Earthquake hazard after a main shock in California, Science, 243, PP1173-1176

Rundle JB, Turcotte, DL, Klein W and editors (1996b) Reduction and predictability of natural disaster, Santa Fe Institute Studies in Science of Complexity

Shahvar P and Zare M (2013) A unified seismic catalogue for the Iranian plateau (1900-2001), Geophysical research letter, vol 84,233-249

Utsu, T,Ogata, Y and Matsu´ura, R (1995) The centenary of the Omori formula for a decay law of aftershock activity, Journal of geophysical reaserch, 43, PP1-33

Utsu T (1961) A statistical study on occurrence of aftershock, Geophys Mag, 30, 521-605

Utsu T (1969) Aftershocks and earthquake statistics (1), J Fac Sci Hokkaido Univ Ser 7(2), 129–195

Wiemer S (2000) Introducing probabilistic aftershock hazard mapping Geophys Res Lett 27:3405–3408

Wiemer S and Katsumata K (1999) Spatial variability of seismicity parameters in aftershock zone Journal of Geophysical research, 104(13), 135-151

Wiemer S, Gerstenberger M and Hauksson E (2002) Properties of aftershock sequence of the 1999, Mw 71, Hector Mine earthquake: Implications for aftershock hazard, Bull Seism Soc Am

Zafarani H and Soghrat M (2012a) “Simulation of ground motion in the Zagros region, Iran using the specific barrier model and stochastic method,” Bulletin of the Seismological Society of America 102