Technical Note

Relationships between Different Earthquake Intensity Scales in Iran

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ABSTRACT

Intensity is one of the useful information in extract earthquake analyzing of a region; then, preparing a complete dataset of them is necessary for each region. One of the best intensity information of the most historical and several instrumental earthquakes in Iran (from year 658 to 1979) was reported in an intensity scale with five degrees. There are also several earthquakes with reported intensity information in other three 12-degree intensity scales. Intensity values of these earthquakes could be more useful, if they are converted to a uniform scale, especially in a recent 12-degree intensity scale. In this study, the intensity values were re-estimated for the earthquakes with different reports of intensity. These estimations were performed based on the definition of both the European Macroseismic Scale to consider the building damages and Environmental Seismic Intensity Scale to consider environment effects.Orthogonal Regression was also selected to estimate the relationships between different reported intensity scales ($0.61 < \sigma < 1.80$). By considering the results of the relationships of this study, the intensity values of Iranian earthquakes with various intensity information, only descriptions, only intensity values, or both of them, could be re-estimated in a uniform intensity scale.

Keywords:
Iran; Intensity scale; Orthogonal Regression; Earthquakes relationship

1. Introduction

Earthquake destruction and damage is one of the most important factors that could be effective on seismologist decisions of each region. In seismology, this factor could be defined as a value called intensity value, which could be a way of studying seismic activity. The most reliable intensity values are the ones determined according to the complete descriptions of each earthquake.

Various types of intensity scales introduced in different periods of time, and in different parts of the world were applied more than the others in each area. In the selected area, Iran, the intensity values were reported in four types of intensity scales; one 5-degree scale (AMS; [1]) and three 12-degree intensity scales, Modified Mercalli (MM: MMI; [2-3]), the Medvedev-Sponheuer-Karnik (MSK; [4]), and the European Macroseismic Scale (EMS; [5-6]). Most earthquake descriptions of this region were reported by Berberian [7-12], Zare and Memarian [13], Ambraseys [14], and Ambraseys and Moinfar [15]. Moreover, a few earthquakes were reported by other authors used in this study, which a list of some articles on these studies is presented in Appendix.

These earthquakes were reported in four types of mentioned intensity scales (AMS, MMI, MSK,

and EMS). Studying on the earthquakes with different reported intensities could be useful to extract the relationships between different intensity scales for converting the intensity values in a unique intensity scale. Then, in this study, all earthquake descriptions and their reported intensity values in different intensity scales were collected from available references. Then, the intensity values of all earthquakes were re-estimated in a new intensity scale. In the following, Orthogonal Regression method was applied to estimate the new relationships to convert various intensity scales to each other. Therefore, re-estimating the intensity values of earthquakes in a uniform intensity scale could be possible in this study.

2. Dataset

Intensity information of Iranian earthquakes was collected from available books, articles, and published reports of different Iranian research centers including International Institute of Earthquake Engineering and Seismology (IIEES), Building and Housing Research Center (BHRC), Geological Survey of Iran (GSI), and National Geoscience Database of Iran (NGDIR).

Two main types of avialable intensity information consist of the descriptions and the values of intensity. From all earthquakes, about 350 earthquakes have different descriptions; some of them with the reported intensity values and some of them without any intensity values. Other earthquakes have only got the reported intensity values without any descriptions. For several earthquakes, the descriptions of some macroseismic data points (MDPs) were also reported. All of this information was used to estimate the relationships.

3. Method

Estimating the relationships between different intensity scales to convert the intensity values in a uniform intensity scale was the main purpose of this study. Ordinary least square is the most popular regression for fitting the data and estimating the parameters [16-20]; however, this regression assumes that the uncertainties of the independent variables are negligible. Orthogonal Regression (OR) or General Orthogonal Regression (GOR) is another regression with the assumption of different uncertainties for each variable [21-22]. To estimate the simple regression between two intensity scales, each one of which has independent uncertainty, the regression method should consider the uncertainties of each variable. Orthogonal Regression could be suitable for this estimation. This method was selected to estimate the relationships between several types of intensity scales which have independent variables.

In seismology, in some cases such as magnitude conversion, the results of OR are more preferable than the ordinary one [23-25]. The basic definition of this regression defined by Fuller [26] and used also by Castellaro et al [21], Lolli and Gasperini [22] and Shahvar et al [27] for earthquake catalogs. In this regression, two main assumptions are considered, in which $\eta = 1$ (OR) and $\eta \neq 1$ (GOR), which obtained by minimizing

$$\sum_{i=1}^{n}\left[\frac{(y_i-\alpha-\beta X_i)^2}{\eta}+(x_i-X_i)^2\right] \quad (1)$$

where α and β are the coefficients, with considering σ as the regression error and $\eta=\frac{\sigma_y^2}{\sigma_x^2}$.

The values of η in our estimation are not 1, then according to Castellaro et al. [21] the general orthogonal estimator of slope is:

$$\beta=\frac{s_y^2-\eta s_x^2+\sqrt{(s_y^2-\eta s_x^2)^2+4\eta s_{xy}^2}}{2s_{xy}} \quad (2)$$

where s_x^2, s_y^2 and s_{xy} are the variance of the x, y, covariance between y and x; and the estimator of the intercept is:

$$\alpha=\bar{y}-\beta\bar{x} \quad (3)$$

where $\bar{x}$ and $\bar{y}$ are the average values of x and y; and their errors are:

$$\hat{\sigma}_{\hat{\beta}}^2=\frac{\hat{\sigma}_x s_\upsilon+\hat{\sigma}_u s_\upsilon-\hat{\sigma}^2_{u\upsilon}}{(n-1)\hat{\sigma}^2_x}$$
$$\hat{\sigma}_{\hat{\alpha}}^2=\frac{s_\upsilon}{n}+\bar{x}^2\hat{\sigma}_{\hat{\beta}}^2 \quad (4)$$

where

$$s_{\upsilon} = \frac{\sum_{i=1}^{n}\left[Y_i - \bar{y} - \hat{\beta}\left(X_i - \bar{x}\right)\right]^2}{(n-2)} = \frac{(n-1)\left(\eta + \hat{\beta}^2\right)\hat{\sigma}_u}{(n-2)}$$
$$\hat{\sigma}_{u\upsilon} = -\hat{\beta}\hat{\sigma}_u \quad (5)$$

$$\hat{\sigma}_x = \frac{\sqrt{(s_y^2 - \eta s_x^2) + 4\eta s_{xy}^2} - (s_y^2 - \eta s_x^2)}{2\eta}$$
$$\hat{\sigma}_u = \frac{s_y^2 + \eta s_x^2 - \sqrt{(s_y^2 - \eta s_x^2) + 4\eta s_{xy}^2}}{2\eta} \quad (6)$$

4. Conversion Intensity Values in Different Scales

All intensity values reported in four types of intensity scales could be more useful if they are re-estimated in a uniform intensity scale, especially if this scale is in a 12-degree scale. Using all available information of the reported intensity values and also considering their descriptions in different scales collected in this study, the relationships between different types of intensity scales were calculated. For each relationship, the earthquakes with values at least in two types of scales were used.

4.1. Re-Estimating the Reported Intensity Scale

Maximum number and descriptions of intensities for earthquakes in Iran, occurred from year 658 to 1979, were reported by Ambraseys and Melville [1]. After introducing MSK intensity scale, for 34 earthquakes of those earthquakes in AMS scale, Ambraseys [14] reported their new intensity values in MSK scale. On the other hand, these 34 earthquakes were reported by Ambraseys [1, 14] in both AMS and MSK intensity scales. With intensity values of earthquakes in four reported intensity scales, the relationships between 5-degree scale of Ambraseys and Melville [1] and other scales were calculated. Results of converting AMS scale to other scales estimated by Orthogonal Regression are presented in Table (1) and Figure (1).

The intensity values of earthquakes, especially in recent decades were reported in 12-degree scales but in different types of scales. Although, there are not many earthquakes reported in different intensity scales, it is possible to estimate the relationships between them with considering those with reported intensities in more than one scale. There are not many earthquakes with the reported EMS scale, but it is possible to estimate it to some of the earthquakes with the descriptions on building damage. Then, these descriptions used to estimate their intensities in EMS scale; and the values applied to calculate the relationships. Results of regression coefficients of converting different types of 12-degree scales reported for Iranian earthquakes are presented in Table (1) and Figure (2).

4.2. Uniform Intensity Scale

Environmental Seismic Intensity (ESI) is another intensity scale introduced to consider environmental effects that are partially neglected in other intensity scales. This scale was introduced by Michetti et al

Table 1. Coefficients of the relationships between different reported intensity scale.

Relationship Between	Beta[1]	Unc_Beta[2]	Alfa[1]	Unc_Alfa[2]	Std[3](x)	Std[3](y)	N[4]
AMS-MMI	1.16	0.07	5.14	1.58	0.74	0.85	88
AMS-MSK	1.36	0.17	5.78	1.75	0.61	0.83	33
AMS-EMS	1.66	0.15	5.10	2.07	0.91	1.52	175
MSK-MMI	0.90	0.11	1.14	6.78	1.02	0.91	32
EMS-MMI	0.69	0.10	1.29	7.26	1.43	0.99	84
EMS –MSK	0.74	0.15	1.28	8.54	1.44	1.06	37

[1] Coefficients of relationship based on the reported intensity values

[2] Uncertainty of coefficients by fitting orthogonal regression

[3] Standard deviation of the x, y series of data

[4] Number of data for each intensity

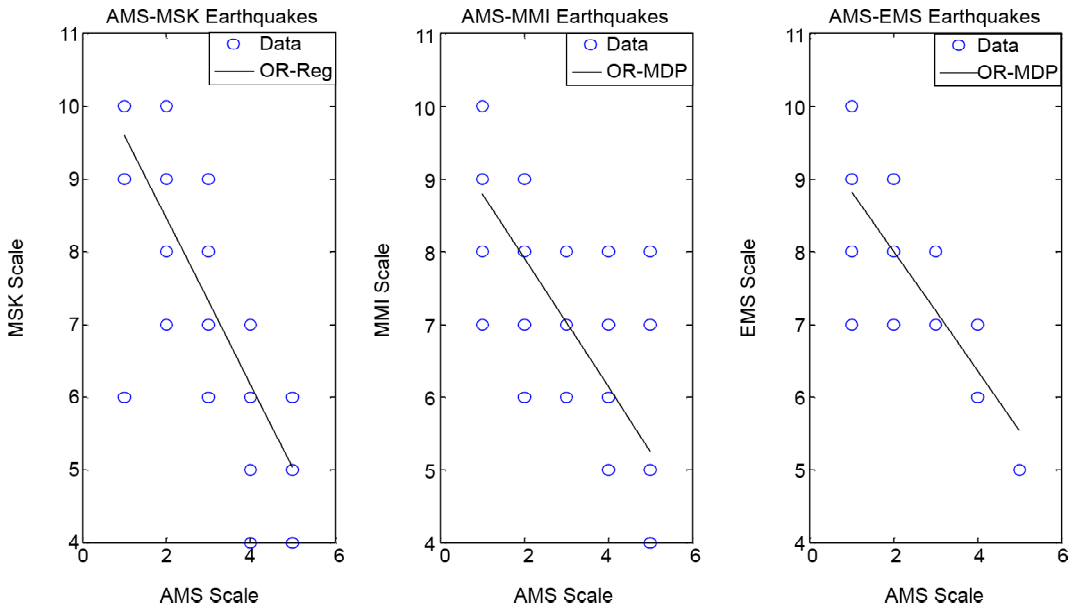

Figure 1. Plot of intensity dataset of AMS intensity scale versus other intensity scales using orthogonal regression; the coefficients are presented in Table (1).

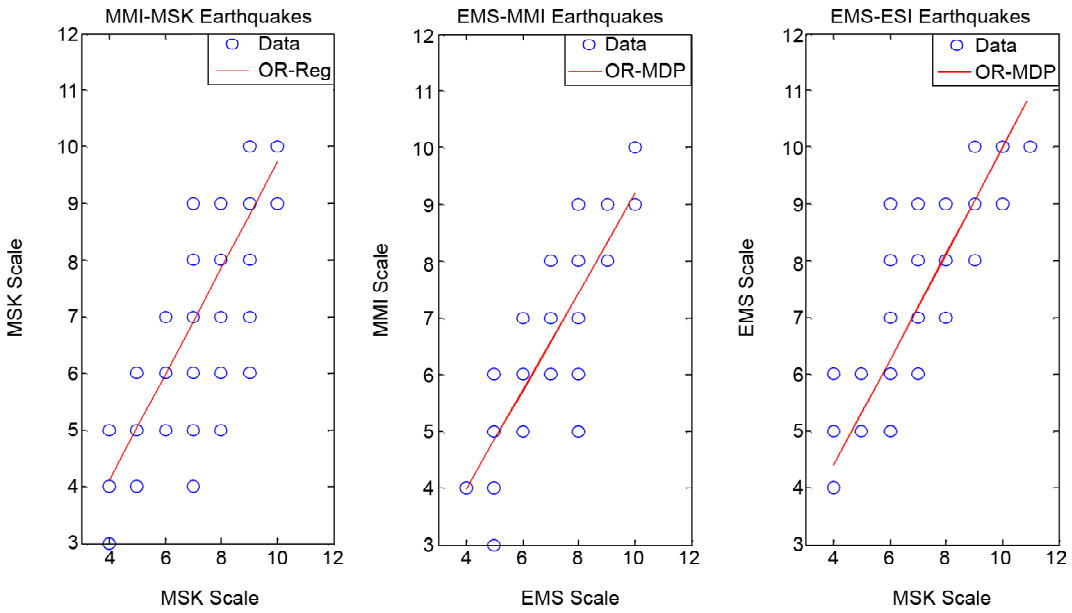

Figure 2. Plot of intensity dataset of MSK, MMI, and EMS intensity scale against each other using orthogonal regression.

[28-29] and has the support of the International Union for Quaternary Research [29] by considering the comparison of three most diffused intensity scales (MCS, MSK, and MM).

Some Iranian earthquakes have several descriptions not on building damages but on environmental effects. To improve the dataset, ESI intensity scale, which was not used for Iranian earthquake before, was also used to re-estimate the relationships and intensity values. On the other hand, by considering the descriptions of both EMS intensity scale as the recent complete scale on building damage and ESI intensity scale to consider environment effects, the new intensity values of earthquakes in Iran were re-estimated using both EMS and ESI scales simultaneously. Then, all reported intensity values could be re-estimated in a uniform scale (called EMS-ESI in this study). Plot of these regressions and their coefficients are presented in Figure (3) and Table (2).

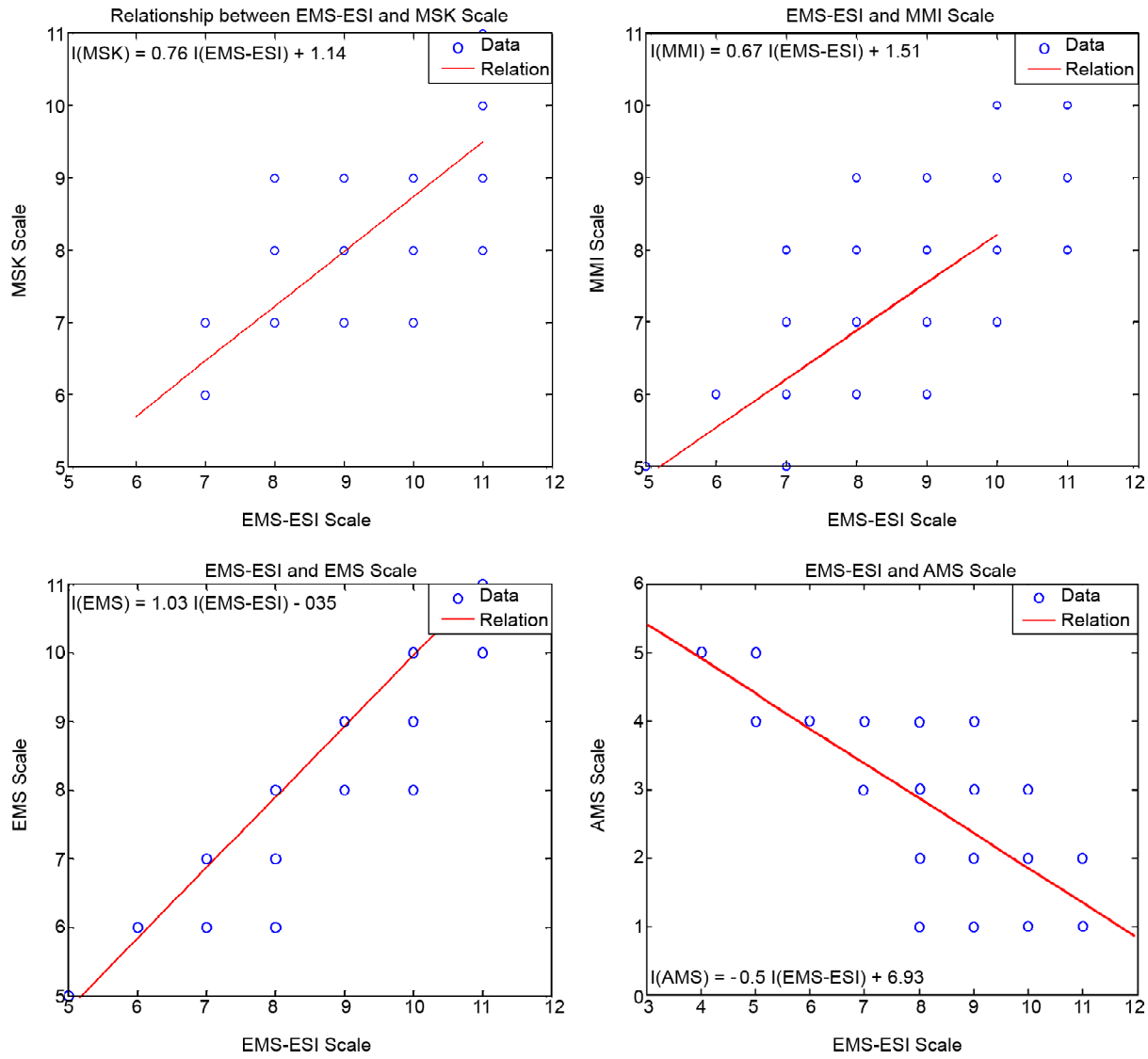

Figure 3. Plot of intensity dataset of all intensity scales versus EMS-ESI intensity scale using orthogonal regression; the slope of relationship between AMS and EMS-ESI scale is different from the others, because the maximum intensity of this scale is 1 instead of 12 in other scales.

Table 2. Coefficients of the relationships between EMS-ESI intensity scale and other reported intensity scales (for more explanation see Table 1).

Related to	Beta	Unc_Beta	Alfa	Unc_Alfa	Std (x)	Std (y)	N
AMS	1.70	0.14	3.67	2.35	1.06	1.80	333
MMI	0.67	0.08	1.51	6.32	1.63	1.10	148
MSK	0.76	0.11	1.14	7.66	1.27	0.96	50
EMS	1.03	0.11	-0.35	7.06	1.51	1.55	250

4.3. Accuracy of Relationships

Re-estimating the new uniform intensity values considering all descriptions could estimate more reliable results. Moreover, estimating the mean of standard deviation of converting each intensity scale showed that the maximum differences of uncertainties belonged to convert MSK scale that could be because of its reports by different authors (Tables 1 and 2). However, with considering EMS-ESI intensity scale, all intensity values could be converted to the values in a unified intensity scale. In converting different scales with respect to

EMS-ESI scale, the range variation of the mean of standard deviations changed between the values 0.96 and 1.80, Table (2) and Figure (4).

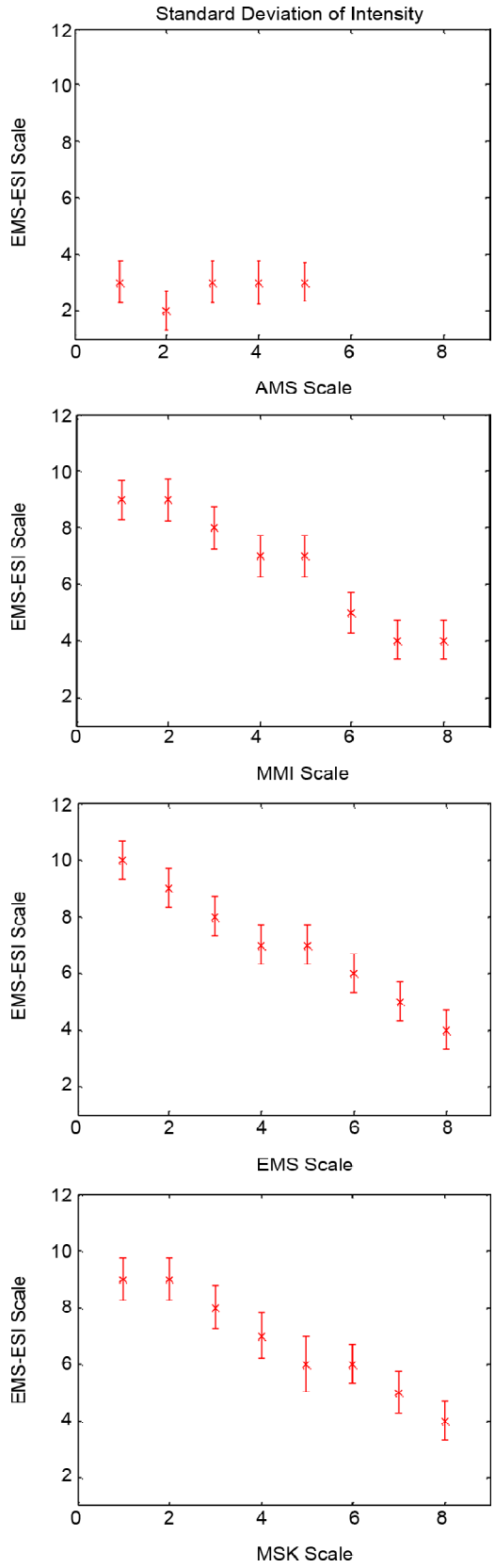

Figure 4. Mean of standard deviation of EMS-ESI intensity scale against other intensity scales; their variations of standard deviation change between 0.61 and 1.8.

5. Conclusion

Intensity information of Iranian earthquakes consist of the earthquakes with only the reported intensity values, with only the descriptions and with both the descriptions and the intensity values. Most of the historical and several instrumental earthquakes, occurred from 658 to 1979, were reported by Ambraseys and Melville [1] in five degrees. Moreover, the intensity values of different instrumental earthquakes were reported in 12-degree scale by different authors; such as MMI scale by Berberian [7-12], MSK scale by Ambraseys [14], and EMS by Zare and Memarian [13].

In this study, Orthogonal Regression (OR/GOR) was selected to estimate the relationships between intensity scales, which their variables are independent. With applying this regression, the relationships between different reported intensity scales and the scale used to convert all intensities to the uniform scale were calculated (Tables (1) and (2)). Based on two intensity scales, EMS scale that considers the building damages and ESI scale that considers environment effects, the intensity values were reestimated in a new and uniform intensity scale called EMS-ESI in this study for the earthquakes in Iran.

In the following, with fitting OR, the new relationships were calculated to convert each type of reported intensity scales to the EMS-ESI scale (Tables 1, 2 and Figures 1 to 4). Range variation of the mean of standard deviation of these conversions, changed between the values 0.61 and 1.80, Table (3) and Figure (4), show that this regression could estimate almost the best intensity values.

Most of the earthquakes are the historical earthquakes reported by Ambraseys and Melville [1] in a 5-degree scale, which were re-estimated in EMS-ESI intensity scale in this study. Although more than 5500 earthquakes with magnitude more than 4 were occurred in this region, according to this study, only 512 earthquakes have the intensity values; therefore, more investigation is necessary to complete the intensity dataset.

6. Data and Resources

International Institute of Earthquake Engineering and Seismology (IIEES) with searching on

www.iiees.ac.ir/fa/eqreports/, Building and Housing Research Center (BHRC) with searching on http://bhrc.ac.ir/, Geological Survey of Iran (GSI) with searching on http://www.gsi.ir/General/Lang_fa, and National Geoscience Database of Iran (NGDIR) with searching on http://www.ngdir.com/Downloads/PDownloadList.asp.

References

1. Ambraseys, N.N. and Melville, C.P. (1982) *A History of Persian Earthquakes*. Cambridge: Cambridge University Press.
2. Richter, C. (1958) *Elementary Seismology*. San Francisco: W.H. Freeman.
3. Wood, H.O. and Neumann, F. (1931) *Modified Mercalli Intensity Scale of 1931*. California: Seismological Society of America.
4. Medvedev, S., Sponheuer, W., and Karnik, V. (1964) Neue seismische Skala Intensity scale of earthquakes, 7. Tagung der Europaischen Seismologischen Kommission vom 24.9. bis 30.9. Veroff Institut für Bodendynamik und Erdbebenforschung in Jena 1964, **77**, 69-76.
5. Grunthal, G. (1993) *European Macroseismic Scale 1992: Updated MSK Scale*. Luxembourg: European Seismological Commission, Subcommission on Engineering Seismology, Working Group Macroseismic Scale.
6. Grunthal, G. (1998) *European Macroseismic Scale 1998: EMS-98*. Luxembourg: European Seismological Commission, Subcommission on Engineering Seismology, Working Group Macroseismic Scales.
7. Berberian, M. (1976) Documented earthquake faults in Iran. *Geol Surv Iran*, **39**, 143-186.
8. Berberian, M. (1976) *Contribution to the Seismotectonics of Iran (Part II): in Commemoration of the 50th Anniversary of the Pahlavi Dynasty*. Tehran: Geological Survey of Iran.
9. Berberian, M. (1976) Quaternary faults in Iran. *Geological Survey of Iran*, **39**, 187-258.
10. Berberian, M. (1977) *Contribution to the Seismotectonics of Iran (Part III): In Commemoration of the 50th Anniversary of the Pahlavi Dynasty. Ministry of Industry and Mines*. Geological Survey of Iran, Tectonic and Seismotectonic Section.
11. Berberian, M. (1981) *Active Faulting and Tectonics of Iran*. 3.
12. Berberian, M. (2005) The 2003 Bam urban earthquake: A predictable seismotectonic pattern along the western margin of the rigid Lut Block, southeast Iran. *Earthquake Spectra*, **21**(S1), 35-99.
13. Zaré, M. and Memarian, H. (2003) Macroseismic intensity and attenuation laws: A study on the intensities of the Iranian earthquakes of 1975-2000. *Fourth International Conference of Earthquake Engineering and Seismology*, 12-14.
14. Ambraseys, N.N. (2001) Reassessment of earthquakes, 1900-1999, in the Eastern Mediterranean and the Middle East. *Geophysical Journal International*, **145**, 471-485.
15. Ambraseys, N.N. and Moinfar, A.A. (1977) Iran earthquake 1968. vol. Publication No. 69. Tehran, Iran: Technical Research and Standard Bureau, Plan and Budget Organization.
16. Boggs, P.T., Spiegelman, C.H., Donaldson, J.R., and Schnabel, R.B. (1988) A computational examination of orthogonal distance regression. *Journal of Econometrics*, **38**(1-2), 169-201, doi:10.1016/0304-4076(88)90032-2
17. Chiaruttini, C. and Siro, L. (1981) The correlation of peak ground horizontal acceleration with magnitude, distance, and seismic intensity for Friuli and Ancona, Italy, and the Alpide belt. *Bulletin of the Seismological Society of America*, **71**(6), 1993-2009.
18. Gasperini, P. and Ferrari, G. (2000) Deriving Numerical Estimates from Descriptive Information: The Computation of Earthquake Parameters.
19. Johnston, A.C. (1996) Seismic moment assessment of earthquakes in stable continental regions - I. Instrumental seismicity. *Geophysical Journal International*, **124**(2), 381-414, doi:10.1111/j.1365-246x.1996.tb07028.x

20. Giardini, D., Di Donato, M., and Boschi, E. (1997) Calibration of magnitude scales for earthquakes of the Mediterranean. *Journal of Seismology*, **1**, 161-180.

21. Castellaro, S., Mulargia, F., and Kagan, Y.Y. (2006) Regression problems for magnitudes. *Geophysical Journal International*, **165**, 913-930.

22. Lolli, B. and Gasperini, P. (2012) A comparison among general orthogonal regression methods applied to earthquake magnitude conversions. *Geophysical Journal International*, **190**, 1135-1151.

23. Ambraseys, N.N. (1990) Uniform magnitude re-evaluation of European earthquakes associated with strong-motion records. *Earthquake Engineering & Structural Dynamics*, **19**, 1-20.

24. Castellaro, S. and Bormann, P. (2007) Performance of different regression procedures on the magnitude conversion problem. *Bulletin of the Seismological Society of America*, **97**, 1167-1175.

25. Gutdeutsch, R., Kaiser, D., and Jentzsch, G. (2002) Estimation of earthquake magnitudes from epicentral intensities and other focal parameters in Central and Southern Europe. *Geophysical Journal International*, **151**, 824-834.

26. Fuller, W.A. (1987) *Measurement Error Models*. New York: Wiley.

27. Shahvar, M.P., Zare, M., and Castellaro, S. (2013) A unified seismic catalog for the Iranian plateau (1900-2011). *Seismological Research Letters*, **84**, 233-249.

28. Michetti, A., Esposito, E., Guerrieri, L., Porfido, S., Serva, L., Tatevossian, R., Vittori, E., Audemard, F., Azuma, T., and Clague, J. (2007) Environmental Seismic Intensity Scale - ESI 2007. *Memorie Descrittive Della Carta Geologica D'Italia*, **74**, 41.

29. Michetti, A.M. (2004) The INQUA scale: an innovative approach for assessing earthquake intensities based on seismically-induced ground effects in natural environment: special paper. System Cart.

Appendix

List of some used articles on different earthquakes for Iran region.

Adeli, H.A. (1981) 14 November 1979 Ghaenat earthquake, Journal of the college of engineering, No. 42, College of Engineering of Tehran University (in Persian).

Adeli, H. (1982) The Sirch (Kerman, Iran) earthquake of 28 July 1981, A final investigation, Bulletin of the Seismological Society of America, **72**(3), 841-861.

Ahmadzadeh, S. (2009) The relation between seismic intensity and building damages during Zarand earthquake (2005), M.Sc. Thesis, Institute of Geophysics, University of Tehran, P. 103 (in Persian).

Alikhanzadeh, R., Solymaniazad, Sh. and Eskandari, M. (2013) Report of Sirch-Kerman earthquake 21 January 2013, Seismotectonic and Seismology group, Geological survey of Iran.

Alinaghi, A.R., Farahbod, A.M., Yamini Fard, F. and Tatar, M. (1997) Preliminary Analysis on Ardekul (Ghaen-Birjand) 10 May 1997, International Institute of Earthquake Engineering and Seismology (in Persian).

Ambraseys, N.N. and Tchalenko, J.S. (1969) The Dasht-e-Bayaz (Iran) earthquake of August 31, 1968: a final report, Bulletin of the Seismological Society of America, **59**(5).

Ambraseys, N.N., Arsovsk, A. and Moinfar, A.A. (1979) The Gisk earthquake of 19 December 1977 and the seismicity of the Kuhbanan fault-zone, UNESCO, FRM/SE/GEO/79/192P.

Ashkpour Motlagh, Sh. and Mostafazadeh, M. (2008) Source Parameters of the Mw 6.6 Fandoqa (SE Iran) Earthquake of March 14, 1998, Journal of Seismology and Earthquake Engineering, Vol. 10, No. 1.

Berberian, M. (1976b) Documented earthquake faults in Iran, Geological and mining survey of Iran, 39, 143-186.

Berberian, M. (1976c) Quaternary faults in Iran, Geological and mining survey of Iran, 39, 187-258,

Berberian, M. (1979) Tabas-e-Golshan (Iran) catastrophic earthquake of 16 september 1978; A

preliminary field report, Pergamon Press Ltd., Printed in Great Bretain, Disasters, Vol. 2, No. 4, pp. 207-219.

Berberian, M. and Navai, I. (1977) Naghan (Chalar MahalBakhtiari - High Zagros, Iran) Earthquake of April 6, 1977: A Preliminary Field Report and Seismotectonic Discussion,in Berberian, M., Contribution to the Seismotectonics of Iran (Part III), Geological and Mining Survey of Iran, Report No. 40.

Berberian M. and Papastamatiou (1978) Khurgu (North Bandar Abbas, Iran) earthquake of March 21, 1977: A preliminary field report and a seismotectonic discussion, Bulletin of the Seismological Society of America, Vol. 68, N 2. , p 411-428.

Berberian, M., Jackson, J. A., Qorashi, M. and Kadjar, M.H. (1984) Field and teleseismic observations of the 1981 Golbaf-Sirch earthquakes in SE Iran, Geophysical Journal of the Royal Astronomical Society, 77, 809-838.

Berberian, M. Qorashi, M., Jackson, J. Priestley, K. and Wallace, T. (1992) The Rudbar-Tarom earthquake of 20 June 1990 in NW Persia: Preliminary field and seismological observations, and its tectonic significance, Bulletin of the Seismological Society of America, Vol. 82, no. 4, pp. 1726 1755.

Berberian, M., Jackson, J.A., Qorashi, M., Khatib, M.M., Priestley, K., Talebian M. and Ghafuri-Ashtiani, M. (1999) The 1997 May 10 Zirkuh (Qa'enat) earthquake (Mw 7.2): faulting along the Sistan suture zone of eastern Iran, Geophysical Journal International, 136, 671-694.

Berberian, M., Jackson, J.A., Fielding, E., Parsons, B.E., Priestley, K., Qorashi, M., Talebian, M., Walker, R., Wright T.J. and Baker, C. (2001) The 1998 March 14 Fandoqa earthquake (Mw 6.6) in Kerman province, southeast Iran: re-rupture of the 1981 Sirch earthquake fault, triggering of slip on adjacent thrusts and the active tectonics of the Gowk fault zone, Geophysical Journal International, 146, 371-398.

Bolourchi, M.J., Solymani Azad, Sh., Faridi, M., Oveisi, B., Qalamqash, J. and Sartipi, A.H. (2012) Primerily report of Ahar-Varzaghan earthquake, Seismotectonic and Seismology group of Tabriz, Geological survey of Iran.

Bolourchi, M.J., Ansari Moghadam, F. and Dorzadeh, H. (2013) Preliminary-Urgent Report of 11 May 2013 Bashagard (Hormozgan), Seismotectonic and seismology department of geological survey of Kerman.

Bolourchi, M.J., Yosefi, T., Kargar, Sh., Alikhanzadeh, R., Farhang, A. and Sedaghat, M. (2013) Preliminary and urgent report of Shoneh earthquake, Boshehr, Seismotectonic and Seismology group, Geological survey of Iran.

Eftekhar nejad, J., Haghi poor, A.A. and Davod zadeh, M. (1968) Studied Report on August 1968 Khorasan earthquake, Geological Survey of Iran (in Persian).

Eshghi, S. and Zare, M. (2003) Bam (SE Iran) earthquake of 26 December 2003, Mw6.5: A Preliminary Reconnaissance Report, Website: http://www.iiees.ac.ir/ English/bam_report_english_recc.html.

Farahbod, A.M., Lindholm, C., Mokhtari, M. and Bungum, H. (2003) Aftershock Analysis for the 1997 Ghaen-Birjand (Ardekul) Earthquake, Journal of Seismology and Earthquake Engineering, Vol. 5, N. 2.

Frotan, M., Shokri, M.A., Javadi Puor, Sh., Oveisi, B. and Bolourchi, M.J. (2010) Primerily report of earthquake 28 August 2010 Tochhi (South Damghan), Seismotectonic and Seismology group, Geological survey of Iran.

Haghipour, A. and Amadi, M. (1980) The November 14 to December 25, 1979, Ghaenat earthquakes of northeast Iran and their tectonic implications, Bulletin of the Seismological Society of America, 70, 1751-1757.

Hollingsworth, J., Jackson, J. Alarc?n, J.E. Bommer, J. and Bolourchi, M.J. (2007) The 4th February 1997 Bojnurd (Garmkhan) Earthquake in NE Iran: Field, Teleseismic, and Strong-Motion Evidence for Rupture Directivity Effects on a Strike-Slip Fault of Iran, Journal of Earthquake Engineering, 11:193-214, ISSN: 1363-2469 print/ 1559-808X online, DOI: 10.1080/13632460601031078.

Hosseini Hashemi, B., Hamzeh lu, H. and Davodi, M. (2005) Preliminary report on 22 February 2005 Dahuieyeh Zarand, International Institute of Earthquake Engineering and Seismology (in Persion).

Khatib, M.M. (1997) Seismic fault geometry analy-

sis on 10 May 1997 Birjand-Ghaen earthquake, Article Summary of 10 May 1997 Birjand-Ghaen earthquake, Birjand University (in Persian).

Mahdavifar, M.R., Solaymani, Sh. and Jafari, M.K. (2006) Landslides triggered by the Avaj, Iran earthquake of June 22, 2002, Engineering Geology, **86**, 166-182.

Memarian, P. and Mahdavifar, M.R. (2012) Distribution and characteristics of landslides induced by the Varzeghan-Ahar earthquake doublet (Mw=6.4 and Mw=6.3) in 2012 in Azerbaijan-e-Sharghi, northwest of Iran, Proceedings of the IPL Symposium, UNESCO, Paris.

Mohajer-Ashjaie, A., Norozi, A.A., Taghi zadeh, Gh.A. and Zohorian, A.A. (1980) Report of two merged earthquakes in Ghaenat (1979), Journal N. 122 (in Persian).

Moinfar, A.A. and Etemadi Eidghahi, M. (1981) Preliminary report on Sirch and Golbaf 1981 earthquake, Engineering earthquake part of Building and Housing Research Center, N. 40 (in Persian).

Moinfar, A.A. and Naderzadeh M. (1990) An immediate and Preliminary Report on the Manjil Iran Earthquake of 20 June 1990, Building and Housing Research Center, Rep. No.119, 68p.

Moinfar, A.A., Naderzadeh, M. and Akhoundi, A. (1994) Lessons learned from the 20 June 1990 Manjil, Iran earthquake, Earthquake Engineering, Tenth World Conference, Balkema, Rotterdam. ISBN 9054100605.

Nikzad, K., Alinaghi, A., Azadi, A., Farahbod, A. and Tiv, M. (1997) The Ardekul, Iran, Earthquake of May 10, 1997, Earthquake Engineering Research Institute special earthquake report.

Nikzad, Kh., Alinaghi, A.R., Azadi, A. and Farahbod, A.M. (1997) Preliminary Analysis on Ardekul (Ghaen-Birjand) 10 May 1997, International Institute of Earthquake Engineering and Seismology (in Persian).

Ramazi, H.R., Niri, A., Khademi, M.H., Yasrebi, F. and Farzanegan, E. (1997) Preliminary- Urgent report on Garmkhan (North Bojnurd), Engineering earthquake part of Building and Housing Research Center (in Persian).

Ramazi, H.R., Mirzaie Alavijeh, H., Farzanegan, E., Yasrebi, F., Mazroie, A., Razaghhi Azar, N. and Majid Zamani, S.S. (1997) Zirkuh-Ghaen (Khorasan) 10 May 1997 earthquake, engineering earthquake part of Building and Housing Research Center (in Persian).

Razaghi Azar, N., Farzanegan, E. and Khademi, M.H. (1994) Preliminary report on Sefidabeh Earthquake 23 February 1994, Sistan- Baluchestan, Report 5, Engineering earthquake part of Building and Housing Research Center (in Persian).

Sarvghad Moghadam, A.R., Hessami Azar, Kh., Mahdavifar, M.R., Javan Dolaie, Gh. and Hamzehlu, H. (2006) Report identification of earthquake 31 March 2006 of Silakhor, International Institute of Earthquake Engineering and Seismology.

Shakib, H., Fatemi Aghda, S.M., Majedi Ardakani, M.H., Taheri, A.R. and Gerami Nia, A.R. (1997) Analyzing Garmkhan-North Bojnurd earthquake, Natural Disaster Research Center, Housing Foundation of Islamic Revolution (in Persian).

Sharp R. and Orsini, N. (1978) Preliminary report on the Tabas, Iran, earthquake of September 16, U.S. Geology Survey.

Talebian, M., Qorashi, M., Nazari, H. and Baharvand, M. (2006) Primarily report of 31 March 2006 earthquake of Silakhor (South Borujerd), Geological Survey of Iran, Ministry of Industries and Mines.

Tatar, M., Yamini fard, F., Bastami, M., Davodi, M. and Parsizadeh, F. (2013) Primarily report of Dashti earthquake 9 April 2013, Boshehr, International Institute of Earthquake Engineering and Seismology.

Tavakoli, Sh., Haeri, S.M. Eshghi, S. and Alijani Moghadam, H. (1990) Preliminary Analysis Num. 1 on 21 June 1990 Manjil-Rudbar (Iran), International Institute of Earthquake Engineering and Seismology, N. 70-91-1 (in Persian).

Walker, R., Jackson, J. and Baker, C. (2004) Active faulting and seismicity of the Dasht-e-Bayaz region, eastern Iran, Geophysical Journal International, 157, 265-282. doi: 10.111/j.1365-2966.2004.02179.x.

Walker, R.T., Bergman, E., Jackson, J., Ghorashi, M. and Talebian, M. (2005) The 2002 June 22 Changureh (Avaj) earthquake in Qazvin Province, northwest Iran: epicentral relocation, source parameters, surface deformation and geomorphology, Geophysical Journal International, 160, 707-720, doi: 10.1111/j.1365-246X.2005.02516.X

Zare, M., Eshghi, S., Alinaghi, A.R. and Tavakoli, Sh. (1994) Earthquake report on Sefidabeh Earthquake 23 February 1994, Sistan- Baluchestan, International Institute of Earthquake Engineering and Seismology (in Persian).

Zare, M. and Javan Doloei, Gh. (2005) Preliminary-urgent report on 22 February 2005 East-Southern East Krman (Hotkan-Dahuieyeh), International Institute of Earthquake Engineering and Seismology (in Persian).