APPLICATION OF STEPP METHOD FOR ASSESSING THE COMPLETENESS OF INSTRUMENTAL AND PRE-INSTRUMENTAL EARTHQUAKE DATA IN DIFFERENT SEISMIC PROVINCES OF IRAN

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ABSTRACT

Seismic hazard assessments are effected by large uncertainties derived from instrumental and pre-instrumental data. One of a significant source of uncertainties is the incompleteness of historical seismic records. Thus, checking the completeness for different magnitude levels is a paramount step in seismic hazard assessment. In this paper STEPP method has been proposed for checking the completeness of seismic catalogues. For this purpose, different de-clustering methods were tested on composite homogenized catalogue of Iran and then Gardner & Knopoff was selected as a final choice for de-clustering the catalogue. Using the STEPP method, the interval in a magnitude class over which the class is complete was determined. After dividing the seismic data, the magnitude of completeness (Mc), defined as the lowest magnitude above which 100% of all events in a given region are detected, is found by maximum curvature method from the complete part of the catalogue.

INTRODUCTION

In active seismic region such as Iran, where earthquake hazard analysis deeply relies on historical and instrumental earthquake data, earthquake catalogs are the most important seismological products. For evaluation of mean annual rate of seismic activity and seismic parameters such as a value and b value, catalogs of historical and instrumental data are used. For different reasons, historical and sometimes instrumental recorded data are incomplete. Then the record threshold must be defined for earthquake data. For historical periods, this factor depends on the intensity of these seismic events and past population density and interest of chronologist who take notice of these events. The incompleteness of instrumental data is due to the geometry and coverage of seismic network. Sometime destruction of some seismographs causes incompleteness in recorded data. Then the assessment of data completeness is a prime factor for any hazard analysis. There are different methods for assessment of intensity and magnitude threshold which catalog can considered complete or to determine time intervals which certain intensity or magnitude range is seems to be complete (Stepp, 1972; Mulargia and Tinti, 1987; Grünthal et al., 1998; Stucchi et al., 2004; Wössner and Wiemer, 2005). The purpose of this article is to determine the time intervals in which the magnitude of data in different seismotectonic zones of Iran are complete and then evaluate the value of magnitude threshold of data completeness.

TECTONIC FRAMEWORK

The Iranian plateau is a part of Alpine-Himalayan belt which has a high level of seismic activity. By merging the seismotectonic maps developed by Mirzaei et al. (1998) and Tavakoli (1996), the country can be divided into six major zones (Fig. 1). The first zone, Alborz, which extended around the South Caspian Sea, is a zone of high seismicity, and strong earthquakes have been recorded in this region. Zagros region is the second one which is one of the most seismically active intracontinental fold and-thrust belts on Earth and an important element in the active tectonics of the Middle East (Talebian and Jackson 2004). The third seismotectonic zone of Iran, Central Iran, located between Alborz and Zagros, which contains some notable active faults such as Doruneh fault. Makran subduction zone and Kopeh-Dagh located in south and north eastern part of Iran respectively are fifth and sixth seismotectonic zones of Iran.

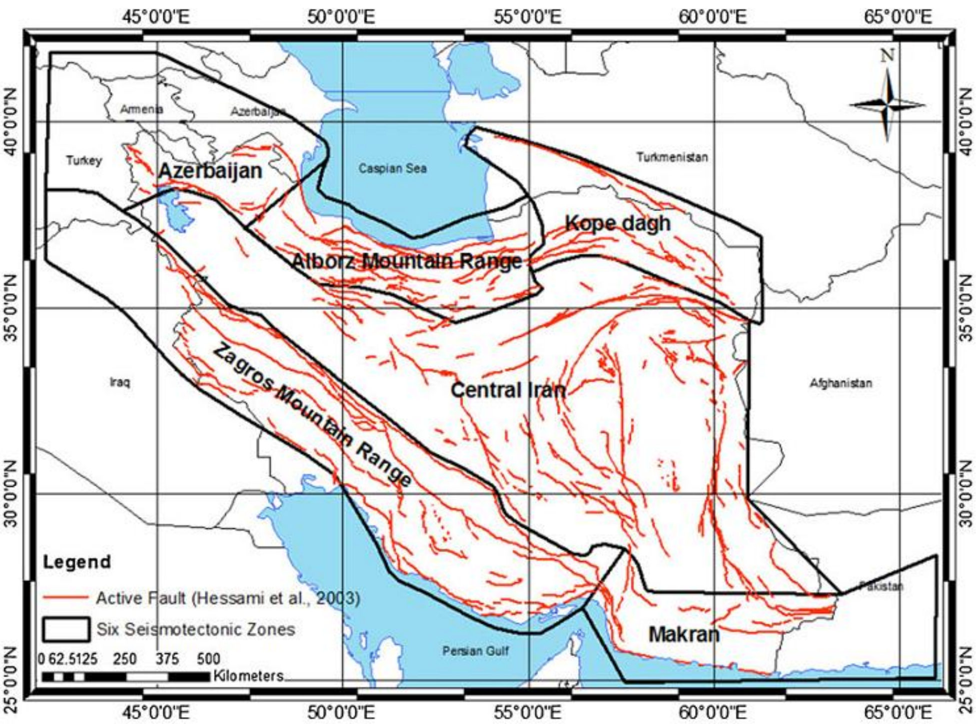

Figure 1. six seismotectonic zones of Iran

DATABASE: COMPOSITE EARTHQUAKE CATALOGUE

The first step in analyzing seismic hazard study is developing a uniform seismic event catalogue for Iran which would be as accurate as possible. For this purpose, all available national and international data banks such as EHB[1], ISC[2], NEIC[3], IRSC[4] and IIEES[5] were used to compile the new catalog. For historical part of catalog, comprehensive historical catalogs which were gathered by Ambraseys & Melville (1982) and Berberian (1994) were applied. A few numbers of paleo-seismic studies around some active faults were used to determine the accurate value of historical earthquake magnitudes. For each event, time, location, magnitude and depth were detected. The compiled catalog uses uniform magnitude, expressed in terms of a standard scale, moment magnitude, Mw.

CompiCat software (compicat.2012) was used for omitting duplicate events. According to this software, events with 60 seconds time differences, 0.01 differences in latitude and longitude, 1 km in depth and 1 unit in magnitude known as duplicate events and depending on prioritize factor, one of them can be removed. Table (1) show an example of duplicate removed from the composite earthquake catalogue.

[1] EHB, Bob Engdahl
[2] International Seismological Center UK
[3] National Earthquake Information Center
[4] The Iranian Seismological Center, University of Tehran
[5] International Institute of Earthquake Engineering and Seismology

Table 1. Examples of duplicate events removed by CompiCat software

Year	Month	Day	Hour	Min	Second	Latitude	Longitude	Depth	Magnitude
1928	12	3	24	21	36	41	45.4	33	4.7
1928	12	3	23	32	41	41	45.4	33	4.7
1929	9	3	24	7	39	26.5	62.25	33	6.52
1929	9	3	23	7	39	26.5	62.25	33	6.52
1936	6	30	19	26	60	33.67	60.45	33	6
1936	6	30	19	26	59	33.67	60.45	33	6
1953	2	12	8	14	60	35.4	55.08	10	6.5
1953	2	12	8	14	59	35.4	55.08	10	6.5

De-clustering the Catalogue

Due to general assumption that earthquakes are poissonian distributed and independent of each other, the recognition and removal of foreshocks and aftershocks from the initial catalogs is a prerequisite for calculating the completeness of the catalog. (Gardner and Knopoff, 1974; Shearer and Stark, 2011). Events which are occurred in a given time interval and distance of a large event are known as dependent events where the spatial-temporal windows vary with magnitude. By de-clustering, dependent events such as aftershocks, foreshocks and swarm events are removed and the number of events removed by de-clustering is affected by the size of the main shock (Omori, 1900, Utsu et al., 1995).

There are four basic methods, Gardner-Knopoff (1974), Gruenthal (pers. Comm.), Reasenberg (1985), and Uhrhamer (1986), for declustering a catalog. In each method, different range of distance and time is considered. This study investigates the Gardner & Knopoff, Reasenberg and Gruenthal declustering methods. Default standard parameter values of Reasenberg's algorithm (1985) are represented in table (2). An approximation of the windows sizes according to Gardner and Knopoff (1974) and Gruenthal is shown in table (3).

Table 2. Default standard parameter values of Reasenberg's algorithm

Parameter	Standard	Simulation Range	
		Min	Max
τ_{min} (days)	1	0.5	2.5
τ_{max} (days)	10	3	15
P	0.95	0.9	0.99
Xmeff	4.0	0	1
Xk	0.5	1.6	1.8
rfact	10	5	20

Table 3. window sizes according to Gardner and Knopoff (1974) and Gruenthal

Method	Distance (Km)	Time (days)
Gardner and Knopoff (1974)	$10^{0.1238+0.983}$	$10^{0.032M+2.7389} \quad , if\ M \geq 6.5$ $10^{0.5409M-0.547} \quad , else$
Gruenthal (pers.comm.)	$10^{1.77+(0.037+1.02M)^2}$	$\lvert e^{-3.95+(0.62+17.32M)^2} \rvert , if\ M \geq 6.5$ $10^{2.8+0.024M} \quad , else$

De-clustering with mentioned methods, show that the maximum and minimum number of remained events belong to Reasenberg and Gruenthal methods, respectively. Since the reasenberg parameters were not modified for seismic data of Iran, it is not that trustfully for applying in seismotectonic regions of Iran. The number of main events which were extracted from initial catalogs in different seismotectonic regions by Gruenthal method was exclusively less than Gardner & Knopoff (1974). Since the number of main events for accurate calculations is important in this study, we selected Gardner & Knopoff (1974) as a preferable de-clustering method in this research.

Table (4) to (9) show the number of clusters and removed events by Gardner & Knopoff de-clustering method for each seismotectonic regions of Iran. Figure2 shows the distribution of earthquakes before and after de-clustering in Alborz seismotectonic zone.

Table 4. Number of clusters and removed events by Gardner & Knopoff method in Alborz

Type of Method	Number of Events	Number of Clusters	Number of Event in Final Catalog	Number of Event Out of Catalog
Gruenthal, pers.comm.	840	149	270	570 (67.85%)
Gardner & Knopoff (1947)	840	148	371	469 (55.83%)
Reseanberg, 1985	840	53	691	202

Table 5. Number of clusters and removed events by Gardner & Knopoff method in Azerbaijan

Type of Method	Number of Events	Number of Clusters	Number of Event in Final Catalog	Number of Event Out of Catalog
Gruenthal, pers.comm.	7153	792	1555	5598 (78.26%)
Gardner & Knopoff (1947)	7153	847	2462	4691 (65.58%)
Reseanberg, 1985	7153	293	5902	1544

Table 6. Number of clusters and removed events by Gardner & Knopoff method in Markazi

Type of Method	Number of Events	Number of Clusters	Number of Event in Final Catalog	Number of Event Out of Catalog
Gruenthal, pers.comm.	2634	321	701	1933 (73.39%)
Gardner & Knopoff (1947)	2634	315	870	1764 (66.97%)
Reseanberg, 1985	2634	195	1932	897

Table 7. Number of clusters and removed events by Gardner & Knopoff method in Makran

Type of Method	Number of Events	Number of Clusters	Number of Event in Final Catalog	Number of Event Out of Catalog
Gruenthal, pers.comm.	610	114	221	389 (63.77%)
Gardner & Knopoff (1947)	610	120	271	339 (55.57%)
Reseanberg, 1985	610	38	519	129129

Table 8. Number of clusters and removed events by Gardner & Knopoff method in Zagros

Type of Method	Number of Events	Number of Clusters	Number of Event in Final Catalog	Number of Event Out of Catalog
Gruenthal, pers.comm.	8256	997	1509	6747 (81.72%)
Gardner & Knopoff (1947)	8256	1288	2319	5937 (71.91%)
Reseanberg, 1985	8256	752	6594	2414

Table 9. Number of clusters and removed events by Gardner & Knopoff method in Kopeh Dagh

Type of Method	Number of Events	Number of Clusters	Number of Event in Final Catalog	Number of Event Out of Catalog
Gruenthal, pers.comm.	586	119	232	354 (60.41%)
Gardner & Knopoff (1947)	586	123	293	293 (50%)
Reseanberg, 1985	586	44	515	115

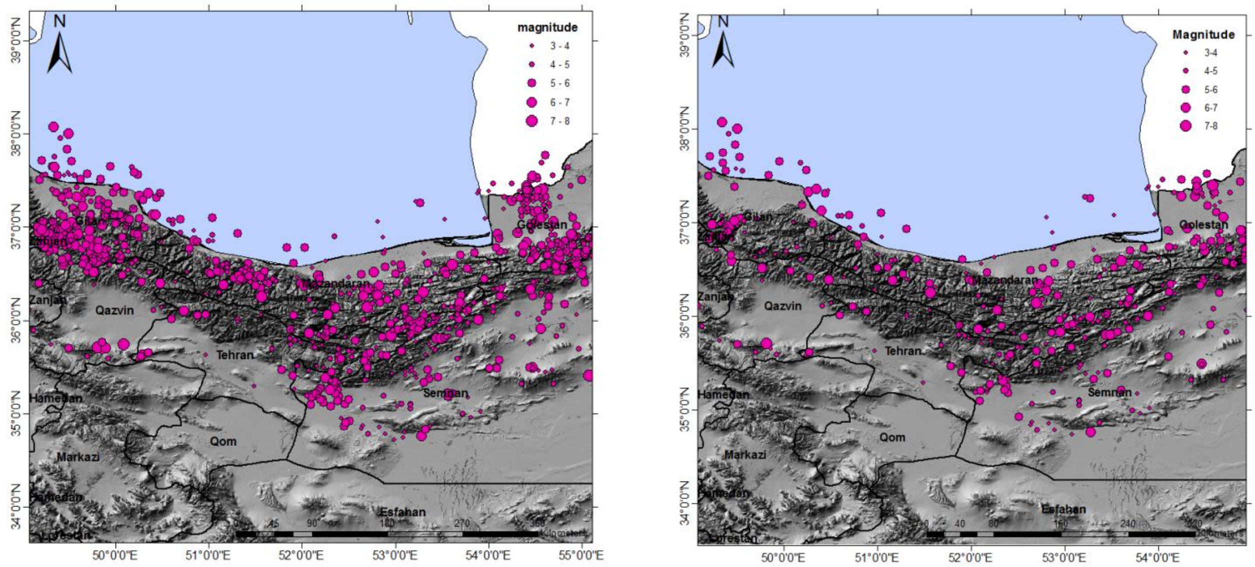

Figure 2. Distribution of earthquakes before and after de-clustering in Alborz seismotectonic zone

ASSESSING CATALOGUE COMPLETENESS

For detecting the time interval in which a magnitude class is complete, the methodology of STEPP (1972) was applied. For each seismic region, the recorded earthquakes are categorized into seven magnitude classes as $3 \leq M_W < 4$, $4 \leq M_W < 5$, $5 \leq M_W < 6$, $6 \leq M_W < 7$, $7 \leq M_W < 8$ and $8 \leq M_W < 9$, with a time interval of 10 years. In each magnitude range, the average number of events per year was determined. If χ_1, $\chi_2, \chi_3, \dots, \chi_n$ are the number of events per year in each magnitude range, mean for these samples are as below:

$$\chi = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Where n is the number of time intervals. The variance is equal to:

$$\sigma_{\chi}^2 = \frac{\chi}{T}$$

T is the duration of the sample, σ_χ would be equal to $\frac{1}{\sqrt{T}}$ if χ is to be constant. As per Stepp (1972) the standard deviations of the mean rate for the each magnitude intervals as a function of sample length are plotted along with nearly tangent lines with slope $\frac{1}{\sqrt{T}}$. The deviation of standard deviation of the estimate of the mean from the tangent line indicates the length up to which a particular magnitude range may be taken as complete (Raghukanth, 2010). Figure 3 shows a typical completeness test, with the standard deviation of the estimate of the mean of the annual number of events as a function of sample length for Alborz seismic region. The analysis shows that data is complete for the sets $4 \leq M_W<5$, $5 \leq M_W<6$, $6 \leq M_W <7$ and $6 \leq M_W$ <7 for the past 40, 60, 60 and 70 years, respectively. Based on the completeness test of magnitude class $4 \leq$ Mw < 5, the data set has been divided into complete part (1973–2013) and extreme part (1100–1972). After dividing the seismicity data, the threshold magnitude (Mc), defined as the lowest magnitude above which 100% of the events in a given region are detected, is found from the complete part of the catalog (Wiemer and Wyss 2000). The Mc is obtained through the regression analysis from the frequency magnitude distribution as the value where the data depart from a straight line (Wiemer and Wyss 2000). Figure 4 shows the frequency magnitude distribution in the complete part of the catalog for the Alborz seismic region. The threshold magnitude obtained from the complete part is around 4.8 (Figure4). Table (10) and (11), show the result of the time interval and magnitude of completeness for different seismotectonic regions of Iran.

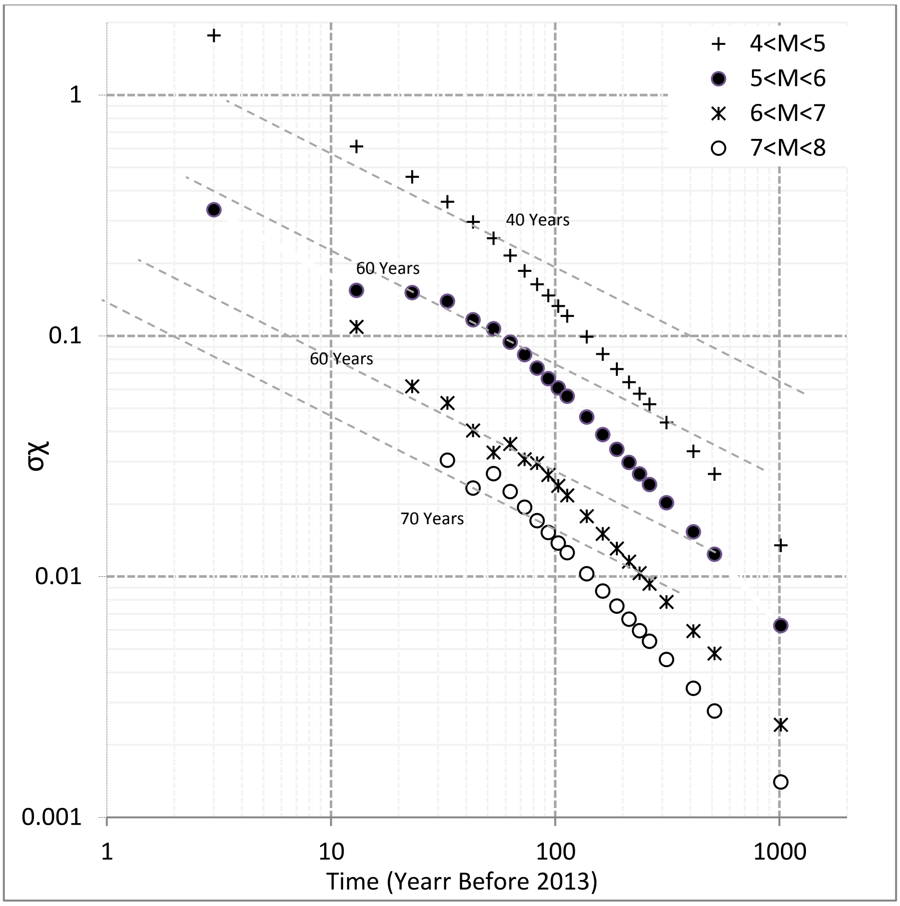

Figure 3. Typical completeness test by STEPP method in Alborz seismotecronic zone

Table 10. Different time intervals for different magnitude ranges in six seismic regions of Iran

	$4 \leq M_W<5$	$5 \leq M_W<6$	$6 \leq M_W <7$	$7 \leq M_W <8$
Alborz	40 (Yr)	60 (Yr)	70 (Yr)	60 (Yr)
Azerbaijan	50 (Yr)	80 (Yr)	80 (Yr)	90 (Yr)
Markazi	40 (Yr)	80 (Yr)	100 (Yr)	100 (Yr)
Makran	40 (Yr)	50 (Yr)	70 (Yr)	70 (Yr)
Zagros	40 (Yr)	50 (Yr)	110 (Yr)	100 (Yr)
Kopeh-Dagh	50 (Yr)	100 (Yr)	100 (Yr)	100 (Yr)

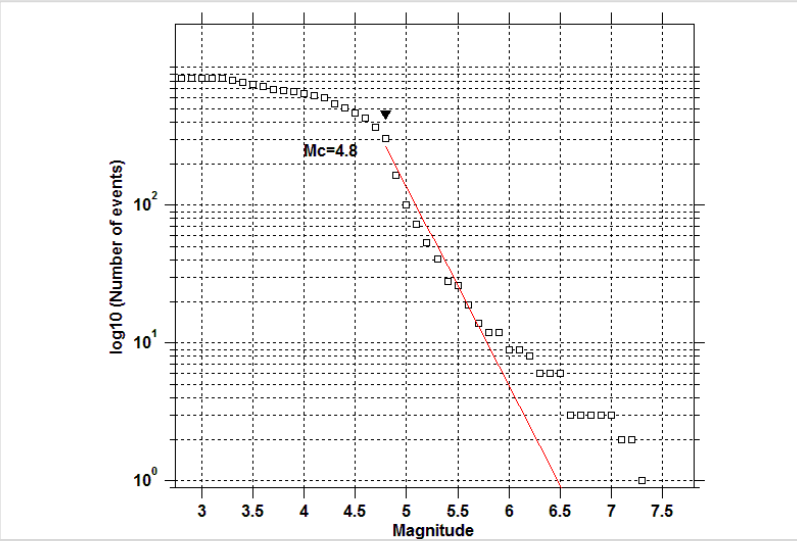

Figure 4. Determining magnitude of completeness by Maximum Curvature method in Alborz seismic region

Table 1. Calculated Mc by maximum curvature method after applying STEPP method

Alborz	Azerbaijan	Markazi	Makran	Zagros	Kopeh-Dagh
4.8	3.9	4.9	4.8	4.7	4.9

CONCLUSION

Analyzing the magnitude of completeness for earthquake catalogue is an essential work for a seismic hazard analysis. In this work, Iran was divided into six seismotectonic zones and earthquake catalogue for each zone were evaluated for their completeness. Before assessing the magnitude of completeness, the composite catalogue was de-clustered by different procedures such as Gardner-Knopoff (1974), Gruenthal (pers. Comm.) and Reasenberg (1985). After comparing the results, Gardner-Konpoff was selected as a final choice for de-clustering the catalogue. The completeness for composite de-clustered catalogue was determined following the method described by STEPP (1972) and time intervals in which different level of magnitudes were completed, were determined. At the end, magnitude of completeness for each seismotectonic zones was determined using maximum curvature method.

REFERENCES

Stepp JC (1972) Analysis of completeness of earthquake sample in the Puget Sound area and its effect on statistical estimates of earthquake hazard. National Oceanic and Atmospheric Administration Environmental Research Laboratories, P., 2001. Die Zentralanstalt für Meteorologie und Geodynamik Boulder Colorado, 80302

Mulgharia F, Gasperini P and Tinti S (1987) A procedure to identify objectively active seismotectonic structures. Bolle tino di Geofisica teorica ed applicata, 29 (114), 147-164

Grünthal G, Mayer-Rosa D and Lenhardt W (1998) Abschät- zung der Erdbebengefährdung für die D-A-CH-Staaten - Deutsch- land, Österreich, Schweiz. Bautechnik, 75/10: 753-767

Stucci M, Albini P, Mirto C and Rebez A (2004) Assessing the completeness of Italian earthquake data. Annals of Geophysics, 47, 659-673

Woessner J and Wiemer S (2005) Assessing the quality of earthquake catalogues: Estimating the magnitude of completeness and its uncertainty. Bulletin of the Seismological Society of America, 95, 684-698.

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

Tavakoli B (1996) Major seismotectonic provinces of Iran. International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, Iran (in Persian)

Talebian M and Jackson J (2004) A reappraisal of earthquake focal mechanisms and active shortening in the Zagros mountains of Iran. Geophys J Int 156(3):506–526

Ambraseys NN and Melville CP (1982), A history of Persian earthquakes. Cambridge University Press, Cambridge, p 219

Berberian M (1994) Natural hazards and the first earthquake catalogue of Iran, historical hazard in Iran prior to 1900. International Institute of Earthquake Engineering and Seismology (IIEES) 1:620

Gardner JK and Knopoff L (1974) Is the sequence of earthquakes in Southern California, with aftershocks removed, poissonian? Bulletin of the Seismological Society of America, 64/5, 1363-1367

Shearer PM and Stark PB (2011). Global risk of big earthquakes has not recently increased. Proceedings of the National Academy of Sciences, 109, 717 – 721

Omori F (1900) Investigation of aftershocks. Report Imperial Earthquake Investigation Committee, 30, 4–29.

Utsu T, Ogata Y and Matsu'ura (1995) The centenary of the Omori formula for a decay law of aftershock activity. Journal of Physics of the Earth, 43, 1-33

Reasenberg P (1985) Second-order moment of central California seismicity, 1969-82, J. Geophys. Res., 90, 5479-5495. 3-18

Uhrhammer R (1986) Characteristics of northern and southern California seismicity: Earthquake Notes, v. 57, p. 21.

Wiemer S and Wyss M (2000), Minimum magnitude of complete reporting in earthquake catalogs: examples from Alaska, the Western United States, and Japan. Bull Seismol Soc Am 90:859–869

Raghukanth STG (2010), Estimation of seismicity parameters for India, Seismological research letters, Vol 81, No. 2, 207-217

Compilation of Catalogue (CompiCat), Vladimir Kossobokov and Alexander Mostinskiy, http://www.mitp.ru/soft/ecp/doc/mainindex.html