Study of inhomogeneous compound Poisson probabilistic models for earthquake occurrence

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Abstract: In accordance with the advantages and disadvantages of the existed probabilistic models for earthquake occurrence and the fundamental principle of earthquake estimation, five types of inhomogeneous compound Poisson Probabilistic models for earthquake occurrence are developed. The essential characteristics and possibly applicable hypothesis of these models are explained. The analytical results of the compound Poison models based on North China earthquake data indicate ‘that inhomogeneous compound Poison models may effectively estimate the non-steady process for earthquake occurrence, but, homogenous Poisson models may not do it.

Key words: Inhomogeneous; Poison probabilistic model for earthquake occurrence; Seismic hazard

0. Introduction

Probabilistic model for earthquake occurrence (EO) is always an important fundamental research object in seismic probabilistic prediction (Lu Yuanzhong etc., 1985), engineering seismic hazard analysis (Gong Ping etc., 1997), and seismic loss estimation (Molchan G M etc., 1970). In the past decades, dozens of models for EO were developed from different perspectives, e.g. the uniform Poisson model (Cornell C. A., 1968), segmenting Poisson model (Hu Yuxian, 1990), time-predictable model (Anagnos T etc., 1984), renewal model (Wang F, 1987), two state model (Wang S B etc., 1993), clustering model (Kagan Y Y, 1973), interaction model (Cornell C A etc., 1993), hybrid recurrence model (Wu S C etc., 1995). However, these models can be divided into two types by analytical perspective for stochastic process:

①To think over counting features of earthquake event series, e.g. segmenting Poisson model;

②To think over time features of earthquake, then to change to discuss counting features of earthquake event series, e.g. time-predictable model.

Fundamental mathematical ideas, hypothesis and application process of all these models have both advantages and disadvantages (Gong P etc., 1997).

While doing engineering seismic design, probability prediction and loss estimation, it is appropriate to discuss the models of probabilistic expression directly from interval feature of stochastic process for engineering anti-seismic design. Interval feature can be reflected by many stochastic process methods, and Poisson process is the most common and extensive used stochastic process. Aperiodicity demonstrated by homogeneity of the uniform Poisson model and segmenting model, cannot efficiently estimate seismic hazard even, say nothing of accuracy of prediction. Then the practive work probably suffers a giant uncertainness, as inhomogeneous phenomena of EO cannot be simulated including elastic rebound theory, accumulation of stress, liberation process, active and dormant period of seismic activity. If the trend of seismic activity can be predicted approximately in a definite time now and future with respect to the abundant seismic data and high level of research, seismic hazard analysis for engineering site are expected to these seismic trend estimation. According to the above circumstances, inhomogeneous compound Poisson probabilistic models for EO which can reflect inhomogeneity of EO are put forward with respect to perspective of interval (counting) feature for stochastic process, and the present paper will compare and analyze homogeneity and inhomogeneity of earthquake in North China.

1. Building of inhomogeneous compound Poisson probabilistic models for EO

In the uniform Poisson model and segment Poisson model, the intensity function is considered non-related to time, discussing to the probability of magnitude P_m and the average frequency of EO ν is separated. Set counting number $\{N_t; t>=t_0\}$ is a independent stochastic variable which is independent with magnitude $\{m_i;i=1,2,\ldots\}$ and occurrence occasion $\{O_i;i=1,2,\ldots\}$ .the counting process of EO is the compound of two stochastic process namely magnitude and EO occasion. This kind of compound Poisson process is not only reflect feature of seismic activity briefly, but simplify the calculation as well. In order to keep perspective continuity with the uniform Poisson model and segment Poisson model, in this EO model intensity function have been no longer homogeneity, and the orderliness assumption is eliminated conditionally， while keeps other prerequisite. So the first type of inhomogeneous compound Poisson probabilistic models for EO is satisfied to Poisson distribution, and its intensity function is

$$\lambda_t = P(m \le x < m_\mu \mid t_0, t) \bullet \nu(t) = P_m \bullet \nu \qquad (1)$$

where v is EO rate with magnitude of $(m_0, m_\mu]$ occurring in time interval of $(t_0, t]$, P_m is EO probability with magnitude of $(m, m_\mu]$ occurring in time interval of $(t_0, t]$, m_0 and m_μ separately are lower limit and upper limit of magnitude in the study district, m is consider to lower limit of magnitude. In theory λ_t is not expected to be continuous and differentiable, and the non-negativity of intensity function λ_t is assured by the non-negativity of P_m and v.

If a definite restrain is taken on the conditions for mutual independence of model (1), EO probability of the next seismic magnitude P_m is expected to be related to magnitude of the last earthquake m', so $P(m \le x \le m_\mu \mid t_0, t)$ in (1) is changed to (2)

$$P(m \le x < m_\mu \mid m', t_0, t) \qquad (2)$$

And it is called the second type of inhomogeneous compound Poisson probabilistic models for EO. This kind of condition restrain can simulate certain EO process appropriately, and reflects certain seismic phenomena. For example, possibility of a big earthquake after another big earthquake in a short time is low, while possibility of a big earthquake after a small earthquake in a short time is existent.

The third type of inhomogeneous compound Poisson probabilistic models for EO is that $P(m \le x < m_\mu \mid t_0, t)$ is changed to (3)

$$P(m \le x < m_\mu \mid m', \Delta t, t_0, t) \qquad (3)$$

where m′ is given magnitude, Δt is elapsed time. (3) is used to demonstrate EO probability with magnitude of $(m, m_\mu]$ occurring in time interval of $(t_0, t]$. This kind of condition loosening is convenient for simulating seismic phenomena from perspective of physical mechanism.

The features of the forth type of inhomogeneous compound Poisson probabilistic models for EO is that EO in future is related to the past k earthquakes. Set N_p earthquakes have been occurred in the past t_0, and the magnitude and the occurrence occasion are separately m_i, O_i, i=1, 2…N_p. The magnitude and the occasion in future earthquakes are related to the past k ($1 \le k \le N_p$) earthquakes, and also obey to inhomogeneous compound Poisson process, so the intensity function is similar to (1), just changing $P(m \le x < m_\mu \mid t_0, t)$ to (4)

$$P(m \le x < m_\mu \mid m_i, o_i, m_{i-1}, o_{i-1}, \ldots, m_{i-k}, o_{i-k}, \Delta t, (t_0, t]) \qquad (4)$$

Where Δt is elapsed time.

Generally time series and magnitude series of aforementioned 4 models are compounded mutual independent. If loosing the condition of independent compound, the general formula of inhomogeneous compound Poisson probabilistic models for EO can be put forward, its intensity function is (5)

$$\lambda_t = \lambda_t(P_m, \nu) \qquad (5)$$

Where P_m and ν are general function meaning included by 4 types of inhomogeneous compound Poisson probabilistic models for EO mentioned above. Thus, they are related to magnitude, occurrence occasion and elapsed time of past i earthquakes etc. It is called the fifth type of inhomogeneous compound Poisson probabilistic models for EO. When magnitude is independent with time series, the four types of inhomogeneous compound Poisson probabilistic models for EO above can be deduced from the fifth. So these four models is the special case of the fifth.

In theory, the general formula (5) can reflect the magnitude and time series of earthquake series accurately and also fully simulate knowing seismic phenomena and mechanism. But it is hardly possible to accurately define the explicit expression of intensity function for earthquake series in certain region just by earthquake events data. Only some assumptions are given, can the explicit expression of intensity function be expressed. For example, assuming earthquake series are independent with time series, then, the common compound Poisson process can be formed. In this model, a basic assumption is existence of the intensity function. Conditions about orderliness and without aftereffect can be eliminated. Also the zero counting probability equaling to 1 can be eliminated. That means the zero counting probability can be not equal to 1.

Because of (5) cannot objectively reflect the known explicit expressions in particular analysis, parameter estimation has a high requirement to events data, calculation may be complicated, or researcher cannot give out an objective explicit expression, say nothing of the efficient estimation to parameters. This article put forward these models just from recognition of completeness of mathematical expression and physical mechanism of seismogenic tectonic system. Although in the first type of inhomogeneous compound Poisson probabilistic models for EO, the assumption that magnitude series are independent with event point process is contrary to our recognition that they are related, this assumption can simplify the calculation. In addition, thinking from mathematical statistics, this type of model with mutual independence assumption need less earthquake events data than other compound models. So this type of model has an extensive use in engineering earthquake, seismic probabilistic prediction and loss estimation analysis. If changing the intensity function to homogeneous, this model will change to the uniform Poisson model and segmented Poisson model. According to inheritability and rebirthability of scientific developing laws, the present paper will utilize a numerical calculation example to demonstrate the first type of Poisson model.

2. Numerical calculation

There have been many studies in seismic zoning, the effect of integrality of seismic data to estimation and research of integrality compensative method, value b, reasonability estimation to seismic parameters such as EO rate and seismic activity period etc. In order to reflect and give prominence to the different feature of homogeneity and inhomogeneity in probabilistic model for EO mentioned in this paper, a easier estimation method is applied in data processing. It is easier to demonstrate and analyze. Considering the selected data should be completive in district, time and magnitude, and also for the significance of data index, the researching region should not be too big. According to the above, we take the seismic list with magnitude $m_0 \geq 4.7$ in region 115°~120° E, 39°~41° N. The completive record can be traced back to very early. Seismic activities are considered to be period or quasi-period. Although different researchers have different recognition, so there is different in the division of period, most of them agree that a seismic activity period can divide into active period and dormant period (Lu Y etc., 1985). There have been 4 seismic period since earthquakes were recorded in North China area (Gao W etc., 1990). And there are two periods which have a completive seismic record since 15^{th} century.

$$\text{The third seismic activity period} \begin{cases} \text{seismic.quiet.period}(1369 \sim 1483) \\ \text{seismic.active.period}(1484 \sim 1730) \end{cases}$$

$$\text{The forth seismic activity period} \begin{cases} \text{seismic.quiet.period}(1731 \sim 1813) \\ \text{seismic.active.period}(1814 \sim ......) \end{cases}$$

Although there are some earthquake absences in the early record, we assume that the seismic series from 1369 to 1992 which m0≥4.7 is completive, and in this area the moderate-strong seismic series from 1369 EO time process coincide with the division of the third and the forth seismic activity period in Reference [Gao Weiming, 1990]. The seismic series in fig. 1 demonstrate non-uniforming of EO time process, and it directly reflect inhomogeneous feature of EO. Something must be pointed out that this paper is just discussing the statistical features and stochastic process of the seismic data, it doesn't include the methods to obtain the seismic data and its accuracy.

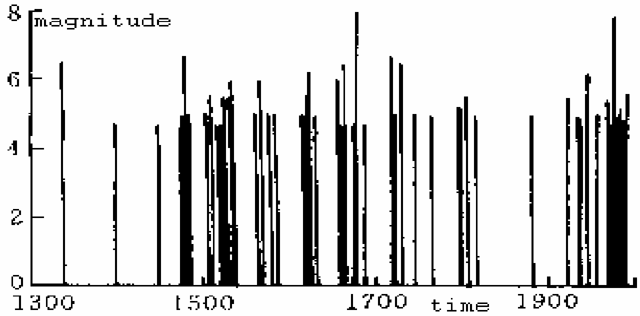

fig. 1 M-T graph during the period 1350 to 1992(M≥4.7)

The recognition of choosing aftershocks has not been coincident, because in mathematics, a Poisson process adds another Poisson process is still a Poisson process. But on another hand, a Poisson process minus a Poisson process may not be a Poisson process. In statistics, counting aftershocks will affect magnitude-frequency relation in small earthquake but the effect is little in large earthquake, and in fact, people care more about the effect of large earthquake. So this paper just demonstrates to analyze, and no choice will be made on the selected seismic series.

The EO probability which exceeds a certain magnitude in certain region can be determined by data, and there will be many expressions. Although inhomogeneous compound Poisson probabilistic models for EO can reflect non-uniform phenomena, it is difficult to describe its inhomogeneous intensity function efficiently. In statistics, we can assume that in the region the EO feature in dormant period and active period can be described by homogeneous compound Poisson probabilistic models for EO, namely homogenizing by time-segmenting simulate the inhomogeneous process of earthquake.

In practical earthquake prediction, estimating the EO probability of certain magnitude is often base on obeying G-R relation. The G-R relation of earthquake frequency can be expressed as (6).

$$\lg N = a - bm \qquad (6)$$

Where a, b are estimative parameters, m is magnitude, N is accumulation number of earthquakes. Tab.1 demonstrate the value of a, b in (6) from seismic data in different period in this region. Annual EO rate(ν) in different magnitude grade related to parameter a, b in different period is demonstrated in Tab.2. And the rate in different period is different.

Tab.1 the value of a, b in (6) from seismic data in different period in the region .

time	earthquake number	earthquake interval	a	b	$\sigma_{\lg N}$	σ_N	R
1369—1484	4	0.3	10.0343	2.00687	0.52139	0.38E-6	0.816
1484—1730	37	0.3	4.26548	0.58267	0.63064	1.88613	0.919
1484—1730	37	0.5	4.01331	0.53385	0.65165	2.50838	0.884
1369—1730	41	0.3	4.32520	0.59141	0.63975	2.49247	0.919
1369—1730	41	0.5	4.07891	0.54340	0.66278	3.49239	0.885
1731—1814	5	0.3	6.29073	1.16495	0.52098	2.50838	0.670
1731—1814	5	0.5	2.78435	0.448~9	0.60861	0.28E-6	0.257
1815—1992	217	0.3	5.70707	0.77581	0.85011	34.5774	0.908
1815—1992	217	0.5	5.71684	0.76339	0.93088	33.8004	0.885
1731—1992	222	0.3	5.74060	0.78065	0.85571	35.5996	0.907
1731—1992	222	0.5	5.75393	0.76864	0.93715	34.2858	0.885
1369—1922	263	0.3	5.59572	0.72182	0.81550	35.2829	0.880
1369—1992	263	0.5	5.52955	0.69924	0.90586	36.4762	0.832

Note: $\sigma_{\lg N}$ is the variance of lgN; σ_N is the variance of N; R is correlation coefficient.

The probabilistic density function when earthquake m occurs from (6) is

$$f(m)=\begin{cases}0 & m>m_\mu \\ \dfrac{\beta\exp(-\beta m)}{[\exp(-\beta m_0)-\exp(-\beta m_\mu)]} & m_0\le m\le m_\mu \\ 0 & m<m_0\end{cases}\qquad(7)$$

Where $\beta=b\ln 10$. The probability of EO in given magnitude of $[m_1, m_2]$ ($m_0\le m_1\le m_2\le m_\mu$) is .

$$P(m_1\le m\le m_2)=\int_{m1}^{m2}f(m)dm=\frac{\exp[-\beta(m_1-m_0)]-\exp[-\beta(m_2-m_0)]}{1-\exp[-\beta(m_\mu-m_0)]}\qquad(8)$$

When $m_0\le m_1\le m_2\le m_\mu$

The probabilistic intensity rate and its intensity function in segmented period can be calculated from (7) and (8).

Tab.2. EO rate(ν) in different magnitude interval and different period in the region .

time	[4.7,8.0]	[4.7,5.2)	[5.2,5.7)	[5.7,6.2)	[6.2,6.7)	[6.7,7.2)	[7.2,7.7)	[7.7，8.0]
1369-1483	0 03418	0 03478	0 00000	0 00000	0 00000	0 00000	0 00000	0 00000
1484-1730	0 14979	0 00311	0 02024	0 01214	0 01214	0 00809	0 00000	0 00404
1369-1730	0.11325	0.07458	0.01381	0 08187	0.08287	0.00551	0.00000	0 00276
1731-1814	0 05952	0 02380	0.03571	0 00000	0.00000	0.00000	0.00000	0.00000
1815-1992	1.21910	0.89325	0.23033	0.06179	0 01685	0.00561	0.00561	0.00561
1731-1992	0.84732	0.61450	0.16793	0.04198	0.01145	0.00381	0.00381	0.00381
1309-1992	0.42147	0.30128	0.07852	0.02243	0.00961	0.00480	0.00160	0.00320

In seismic hazard analysis and seismic prediction analysis, not only the parameters above should be estimated, but also the number of earthquake in certain magnitude and in a certain period should be estimated. In fact, seismic activity intensity in certain period may change with time. For example, when analyzing the trend of seismic activity in North China, Gao Weiming(1990) conjectured future and believed that “The peak of this active period has passed, but this active period still remains 40 to 50 years. And this period may end in 1994 and the last end of the period may end until 2030.” It is appropriate to infer the result by inhomogeneous compound Poisson probabilistic models for EO. This paper simulates counting feature in certain magnitude and in different period for comparison. Now we use values in tab.1 and tab.2 to induce its intensity function.

When $m_0\le m_1\le m_2\le m_\mu, t_1<t\le t_2$, set the general expression of time- homogeneous intensity function λ in period of $(t_1,t_2]$ and magnitude of $(m_1,m_2]$,and $b=b(t)$,$v=v(t)$, then is

$$\lambda=\frac{\exp[-\ln10(m_1-m_0)b]-\exp[-\ln10(m_2-m_0)b]}{1-\exp[-\ln10(m_\mu-m_0)b]}\bullet\nu(t)\qquad(9)$$

According to (9), intensity function is related to v,b,m_0, m_0, m_μ, $m_\mu-m_0$, m_1, m_2, m_2-m_1. Three kinds of intensity function can be formed from tab.1 and tab.2.

Form 1. The parameters of intensity function are that: during 1484~1730, take m_0=4.7, m_μ=8.0, v=0.14979, b=0.53385, during 1731~1814, take m_0=4.7, m_μ=5.6, v=0.05923, b=1.16495, during 1815~1992, take m_0=4.7, m_μ=8.0, v=1.21910, b=0.77581. So when magnitude is in $(m_1,m_2]$ intensity function is.

$$\lambda = \begin{cases} 5414.0997[\exp(-1.78636m_1) - \mathrm{ex}(-1.78636m_2)] \\ \quad 1815 < t \le 1992; 4.7 \le m \le 8.0 \\ 19429.71399[\exp(-2.68238m_1) - \exp(-2.68238m_2)] \\ \quad 1731 < t \le 1814; 4.7 \le m \le 5.6 \\ 49.22564[\exp(-1.22925m_1) - \exp(-1.22925m_2)] \\ \quad 1484 < t \le 1730; 4.7 \le m \le 8.0 \end{cases} \tag{10}$$

Form 2. At period of 1369~1992: the parameters of intensity function are that: during 1369~1730, take m_0=4.7, m_μ=8.0, v=0.11325, b=0.59141, during 1731~1992, take m_0=4.7, m_μ=8.0, v=0.84732, b=0.78065. So when magnitude is satisfied to $m_0 \le m_1 \le m_2 \le 8.0$ the time-segmenting homogeneous intensity function is

$$\lambda = \begin{cases} 3965.250[\exp(-1.79752m_1) - \exp(-1.79752m_2)] \\ \quad 1731 < t \le 1992 \\ 68.95140[\exp(-1.36177m_1) - \exp(-1.36177m_2)] \\ \quad 1369 < t \le 1730 \end{cases} \tag{11}$$

Form 3. At period of 1369~1992: the parameters of intensity function are that: take m_0=4.7, m_μ=8.0, v=0.42147, b=0.72182, so when magnitude is satisfied to $m_0 \le m_1 \le m_2 \le 8.0$ the time-segmenting homogeneous intensity function is

$$\lambda = 1045.0149[\exp(-1.66205m_1) - \exp(-1.66205m_2)] \tag{12}$$

According to (10) to (12), we can conclude that intensity function has features below: ① while $\Delta m = m_2 - m_1$ increases ,λ_t also increases, ②the intensity function is with subjectivity, and this subjectivity demonstrates for period division and certainty of seismic activity parameters in different period. And the estimation to the future seismic activity parameters is also subjective. the efficient method to decrease this subjectivity is to fully understand seismic activity laws of research region.

Tab.3 The intensity function λ_t in different magnitude and period.

Time	[4.7,8.0]	[5.2,8.0]	[5.7,8.0]	[6.2,8.0]	[6.7,8.0]	[7.2,8.0]	[7.7,8.0]	[7.9,8.0]	note
1815-1992	1.21910	0.49705	0.20148	0.08048	0.03096	0.01058	0.00238	0.00065	#
1731-1814	0.05923	0.01119							#
1484-1730	0.14979	0.07980	0.04194	0.02147	0.01040	0.00441	0.00117	0.00034	#
1731-1992	0.84732	0.34358	0.13852	0.05505	0.02107	0.00724	0.00161	0.00044	*
1369-1730	0.11325	0.05669	0.02806	0.01357	0.00623	0.00252	0.00064	0.00018	*
1369-1992	0.42147	0.18260	0.07855	0.03322	0.01348	0.00488	0.0013	0.00031	$

Note: # from (10), * from (11), $ from (12);

In seismic prediction or seismic hazard analysis, the probability of exceeding certain magnitude (m′) is often needed, in fact it is the probability of $m' \le m \le m_\mu$. According to (10) to (12), tab.3 presents the intensity function λ_t related to magnitude of [4.7,8.0], [5.2,8.0], [6.2,8.0], [6.7,8.0], [7.2,8.0], [7,8.0], [7.9,8.0] in different period.

Tab.4. The probability of exceedance per year about λ_t with different time interval.

time	m≥4.7	m≥5.2	m≥5.7	m≥6.2	m≥6.7	m≥7.2	m≥7.7	m≥7.9	note
1815-1992	0.70450	0.39167	0.18248	0.07732	0.03048	0.01062	0.00237	0.00065	#
1731-1814	0.05778	0.01112							#
1484-1730	0.13911	0.07669	0.04107	0.02124	0.01034	0.00440	0.00116	0.00033	#
1731-1992	0.57143	0.29077	0.12935	0.05356	0.02084	0.00721	0.00160	0.00043	*
1360-]730	0.10707	0.05511	0.02766	0.01347	0.00621	0.00251	0.00063	0.00017	*
1369-1992	0.34391	0.16689	0.07554	0.03267	0.01338	0.00486	0.00112	0.00030	$s

Note: the meaning of signs #,*,$ is the same with tab.3

Tab.5 The probability of exceedance in future 50 years for different seismic parameter with different time interval.

Time	m≥47	m≥5.2	m≥5.7	m≥6.2	m≥6.7	m≥7.2	m≥7.7	m≥7.9	note
1815-1992	0.99999	0.99999	0.99996	0.98212	0.78733	0.41371	0.11219	0.03198	a
1790-1839	0.99999	0.99999	0.99351	0.86628	0.53884	0.23433	0.05776	0.01612	b
1731-1814	0.94826	0.42851							c
1706-1755	0.99462	0.89718	0.64954	0.41535	0.22895	0.10439	0.02883	0.00846	d
1484-1730	0.99944	0.98150	0.87717	0.65819	0.40548	0.19788	0.05682	0.01686	e
1731-1992	0.99999	0.99999	0.99902	0.93623	0.65128	0.30372	0.07735	0.02176	f
1706-L755	0.99999	0.99995	0.98446	0.82013	0.49465	0.21651	0.05469	0.01538	g
1369-1730	0.99653	0.94125	0.75414	0.49262	0.26765	0.11838	0.03149	0.00896	h
1369-1992	0.99999	0.99989	0.98031	0.81005	0.49033	0.21651	0.05493	0.01538	i

Note: a, b, c, d, e are respectively from (10), f, g, h are respectively from (11), i is from (12).

According to values in tab.3, we can conclude that the difference in division to seismic activity in 1369~1992 leads to the difference of intensity function value. Clearly, the intensity function value which regards as homogeneous in 1369~1992 is lower than that which regard as active period in 1369~1992. It demonstrates that homogeneous intensity function cannot objectively reflect the feature of seismic active period and dormant period, but inhomogeneous intensity function can.

According to tab.3, the probability that at least 1 earthquake ($N_t \geq 1$) occurred in the relevant magnitude and in the year of $(t_0,t]$ is

$$P\{N_t \geq 1 \mid (t_0, t]\} = 1 - P(N_t = 0) = 1 - \exp(-\int_{t0}^{t} \lambda_\tau d\tau) \qquad (13)$$

The results calculated by different period are demonstrated in tab.4,tab.5 and fig 2.

According to tab.4, the probability of EO of time-segmenting homogeneous and the whole-time homogeneous are different. Time-segmenting can reflect the feature that the probability of EO changes with time, but the whole-time cannot. According to tab.5 and fig.2, when value b and v change in predicted period, such as curves b, d, g in Fig.2, the predicted probability of EO is different with the probability in a,c,e,f,h,i, and it reflects the feature of inhomogeneous intensity function.

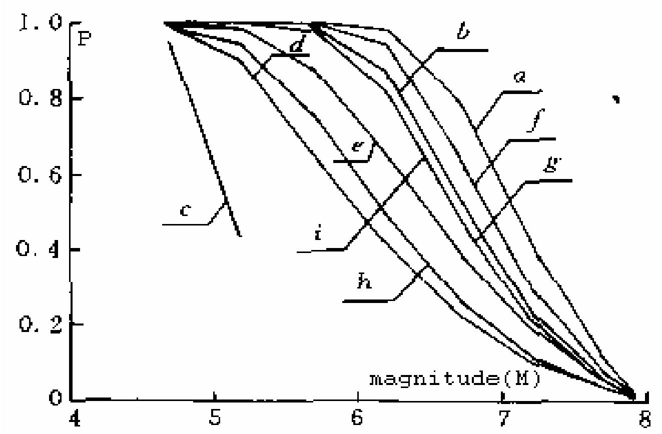

Fig.2 The probability of exceedance in future 50 years for different seismic parameter.

3. Conclusion

(1) Under the case of the same original error and uncertainty, discussing probability of EO from interval feature of stochastic process directly is better than discussing seismic activity indirectly.

(2) The first type of inhomogeneous compound Poisson probabilistic models for EO maybe contrary to the physical mechanism analysis related to magnitude and occurrence occasion. But it is easy to calculate, and it can simulate non-uniform phenomena in EO, and the uniform Poisson model, segmenting Poisson model can be taken as its special case.

(3) Inhomogeneous compound Poisson probabilistic models for EO are better than homogeneous compound Poisson probabilistic models for EO because the former can simulate the non-uniform process in EO while the latter cannot.

(4) No matter inhomogeneous compound Poisson probabilistic models for EO or homogeneous compound Poisson probabilistic models for EO, the efficient estimation to parameters is very important in prediction, and it can directly affect the reliability of the result. The efficient estimation of seismic activity parameters is related to the level of the recognition to seismic activity feature in relevant region, extrapolating principles and estimation counting methods.

Reference (omit)