Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.II)

2-1-8

PROBABILISTIC DESCRIPTION OF EARTHQUAKE OCCURRENCES FOR SEISMIC HAZARD ANALYSIS

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SUMMARY

In this paper, 3 types of estimation methods on earthquake occurrences are proposed, i.e., (1) Extreme value distributions of earthquake occurrences on annual maximum magnitude, (2) Those on annual maximum magnitude and epicentral distance and (3) Simultaneous distributions of earthquake occurrences on magnitude and epicentral distance. Those methods can be available for estimation methods of seismic input for regional aseismic prevention planning of buildings using seismic limit analysis.

INTRODUCTION

In order to evaluate the seismic capacity of buildings, it is necessary to estimate the earthquake occurrence probability in an area around their given site. For seismic risk analysis many probabilistic models for earthquake occurrences are proposed. They mainly dealt with maximum expected values of strong earthquake ground motion and its return period (Ref.1). But probabilistic models are only taken into account of earthquake magnitude and the effect of epicentral distance can not be developed thoroughly (Refs.2,3). On the other hand the authors have already presented the Earthquake Limit Response Analysis method (Refs.4,5,6) and applied it to seismic capacity evaluation, seismic damage prediction and seismic structural design of buildings using probability and fuzzy set theories. In this paper estimation methods on earthquake occurrence probability for those analyses are shown around Kobe City (Ref.7).

EARTHQUAKE OCCURRENCE DATA

In this paper earthquakes are classified into 2 types, i.e., intra-plate earthquakes and inter-plate earthquakes and the observation site is settled at Kobe City (135.2°E,34.7°N) as an example. Earthquake occurrences are estimated by each observed data, respectively.

Intra-plate earthquake Earthquake occurrence data are compiled from JMA earthquake data catalog for the period of 57 years from 1926 through 1982 (Refs.8,9). In those data earthquakes which occurred in the area from 132°E to 138°E and from 32°N to 38°N are used. Furthermore intra-plate earthquakes are selected as follows: a) Earthquakes occurred at the inside of the plate and within a circular area with radius 200 km around Kobe City, b) Shallow earthquakes (focal depth was less than 60 km). The distribution of observed earthquake occurrences for intra-plate type is shown in Fig.1.

Inter-plate earthquake Earthquake occurrence data are compiled from Utsu's earthquake data catalog, which complies the earthquake occurrence data near Japan from 1886 through 1980. In those data earthquakes which occurred for the period of 75 years from 1906 through 1980 (Refs.10,11) are used. Furthermore inter-plate earthquakes are selected as follows: a) Earthquakes occurred in sea area and within a circular area with radius 2000 km around Kobe City, b) Shallow earthquakes. The distribution of observed earthquake occurrences for inter-plate type is shown in Fig. 2.

FREQUENCY DISTRIBUTION OF EARTHQUAKE MAGNITUDE

Generally, following the empirical relation, Gutenberg and Richter's equation (Ref.12), between magnitude M and the number N(M) of earthquakes of magnitude larger than M which occurred at a given area is expressed by

$$\log N(M) = a + b \cdot M \quad (1).$$

Relations between M and N(M) are shown in Fig.3 for both earthquake types. As the results of regression analyses regression coefficients a and b and correlation coefficient r are shown in Table 1. For regression analyses magnitude $M \geq 4$ for intra-plate earthquake and $M \geq 6$ for inter-plate earthquake are used.

EXTREME VALUE DISTRIBUTION OF EARTHQUAKE OCCURRENCE

At first, using the earthquake occurrence data prepared at chapter 2, extreme value distributions (Ref.13) of earthquake occurrences on annual maximum magnitude are shown in Fig.4 for intra- and inter-plate earthquakes, respectively. Cumulative frequencies of maximum magnitude greater than M in magnitude are plotted on Weible's probability paper in Fig.4. In this case only the maximum values of M per year are taken into account. Regression analysis for following equation (Eq.2) are carried out and the results of those using the method of least square are shown in Table 2 for both earthquake types, respectively.

$$\ln[\ln\{1/(1-y)\}] = a + b \cdot M \quad (2)$$

where y is cumulative earthquake occurrence probability greater than M and a, b are regression coefficients and r is correlation coefficient.

Secondly, extreme value distributions of earthquake occurrences within the pitches of epicentral distance are estimated. In this method earthquake occurrence area is divided into some annular zones, i.e., for intra-plate earthquake 10 annular zones by concentric circles with an interval of 20 km from the observation site and for inter-plate earthquake 9 zones by those with an interval of 200 km from the point 150 km far from the observation site. For each annular zone regression analyses on Eq.(2) are carried out. The results are shown in Figs.5,6 with regression lines and the results of the regression analysis using the method of least square are shown in Table 3 for both earthquake types, respectively. Using the recurrence coefficients of Eq.2 in Table 3, contour lines with the same earthquake occurrence probability are illustrated in magnitude(M)-epicentral distance (Δ) plane in Fig.7. In its center values of Δ in each annular zone are adopted as the central values and the linear interpolation method between the each zone is adopted.

Simultaneous Probability Distribution of Earthquake Occurrence

Generally, characteristics of earthquake ground motion are described by earthquake magnitude M and epicentral distance Δ. In this chapter simultaneous probability distributions of earthquake occurrences are estimated as following procedures regarding M and Δ as random variables.

(a) For earthquake occurrence data M and Δ are limited to $M_1 \leqq M \leqq M_s$ and $0 \leqq \Delta \leqq \Delta_s$, where M_1 and M_s are lower and upper bounds of M and Δ_s is upper bound of Δ.
(b) M-Δ planes in (a) are divided into sections. Interval for M is 0.1. That of Δ is 10 km for intra-plate and 100km for inter-plate earthquakes, respectively.
(c) Cumulative frequency of $M \geqq M_i$ and $\Delta_j \geqq \Delta$ is evaluated for each divided section area (M_i, Δ_j).
(d) Using the results of frequency distribution in (c) probability distributions are plotted as shown in Figs.8(a),9(a).
(e) In order to make multiple regression analysis, probability density function f(M,Δ) is assumed for both earthquake types as follows.

$$f(M,\Delta) = a\,(M_s - M)^k + b \cdot \Delta^2 \qquad (3).$$

Probability distribution function F(M,Δ) is derived from following integration on Eq.(3).

$$F(M,\Delta) = \int_M^{M_s} \int_0^{\Delta} f(m,\delta)\,d\delta\,dm \qquad (4).$$

Consequently,

$$F(M,\Delta) = a \cdot \Delta \cdot (M_s - M)^{k+1}/(k+1) + b \cdot (M_s - M) \cdot \Delta^3/3 \qquad (5).$$

(f) Using the cumulative probability distributions of observed data in (d) multiple regression analyses on Eq.(5) are carried out, where M_1=4.0, M_s=7.5 and Δ_s=200 km for intra-plate earthquake and M_1=6.0, M_s=8.5 and Δ_s=2000 km for inter-plate earthquake. Regression coefficients are shown in Table 4 and distributions of F(M,Δ) and f(M,Δ) are shown in Fig.8(b),(c) and Fig.9 (b),(c), respectively.

CONCLUDING REMARKS

Judging from Figs.1,2 the locations of earthquake epicenters are not distributed uniformly around the given area. In case of intra-plate earthquakes many earthquakes occurred near Wakayama Prefecture and in case of inter-plate earthquakes the locations of earthquake epicenters are distributed along the subduction areas of plates locally.

Figs.4,5,6 show that the extreme value distributions of earthquake magnitudes have good coincidence with the Weible-distribution for both earthquake types. In case of Fig.4 annual probability or return period of earthquake occurrences with maximum magnitude can be available only in given whole areas and in case of Figs.5,6 the effects of epicentral distances can be taken into account. Judging from Fig.7 when epicental distance is far the maximum value of M has higher value for the same annual probability of earthquake occurrence in case of intra-plate earthquake and in case of inter-plate earthquake that of M has the lowest value when epicentral distances are between 500 and 1500 km. In comparison with the regression results in Tables 2,3 'a' values in Table 2 are larger than those in Table 3. These methods treat the maximum value of earthquake magnitudes, so the results of seismic risk analyses using these methods are predicted in the safe side. As an application example of these methods, in Ref.5 the linguistic evaluations of seismic input are carried out taken into account of earthquake magnitude, epicentral distance, return period and the life time of buildings using fuzzy set theory.

Figs.8,9 show that the effects of epicentral distance can be roughly taken into consideration. This method may be used as probabilistic model of earthquake occurrences taken into account of locality of those and epicentral distances. Using Eq.(3) and the regression results in Table 4, earthquake occurrence probabilities for seismic risk analyses are estimated freely. As an application example, in Ref.6 the seismic failure probability of buildings is calculated using earthquake occurrence probability estimated this method and failure probability of buildings.

These 3 types of estimation methods on earthquake occurrences are proposed and the results are available for estimation methods of seismic input for regional aseismic prevention planning of buildings.

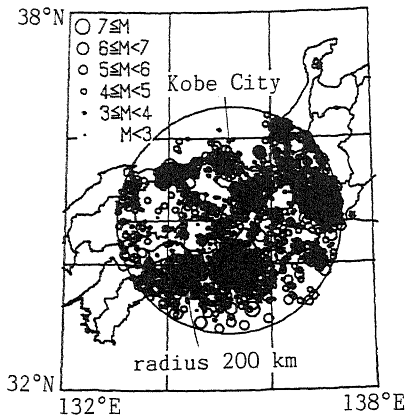


Fig.1 Observed Earthquake Occurrence Distribution of Intra-plate Earthquake

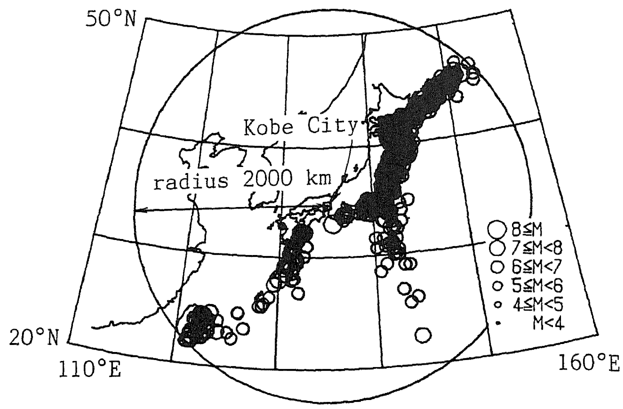
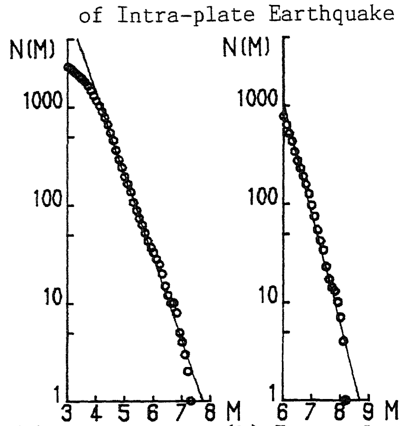
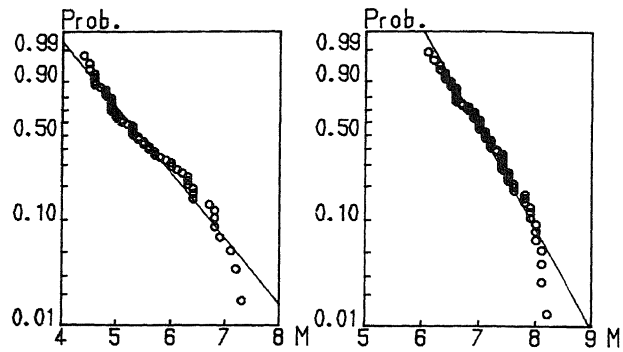


Fig.2 Observed Earthquake Occurrence Distribution of Inter-plate Earthquake



(a) Intra-plate Earthquake (b) Inter-plate Earthquake

Fig.3 Frequency Distributions of Earthquake Magnitude



(a) Intra-plate Earthquake (b) Inter-plate Earthquake

Fig.4 Extreme Value Distributions of Earthquake Magnitude

Table 1 Regression Coefficents of Gutenberg-Richter's Formula in Eq.(1)

Intra-plate Earthquake				
M	a	b	r	Number of Data
M≧4.0	6.54	-0.847	0.995	1160
Inter plate Earthquake				
M	a	b	r	Number of Data
M≧6.0	9.76	-1.12	0.983	771

Table 2 Regression Coefficents of Extreme Value Distribution in Eq.(2)

Intra-plate Earthquake			
a	b	r	Number of Data
7.54	-1.46	0.976	57
Inter-plate Earthquake			
a	b	r	Number of Data
15.2	-2.21	0.976	75

Table 3 Regression Coefficents of Extreme Value Distribution taken into account of Epicentral Distance in Eq.(2)

Intra-plate Earthquake					Inter-plate Earthquake				
Region of Δ (km)	a	b	r	Number of Data	Region of Δ (km)	a	b	r	Number of Data
0<Δ≦20	2.89	-1.32	0.962	19	150<Δ≦350	2.28	-0.791	0.950	7
20<Δ≦40	5.55	-1.75	0.979	37	350<Δ≦550	11.1	-1.94	0.982	36
40<Δ≦60	5.45	-1.49	0.949	50	550<Δ≦750	14.9	-2.40	0.964	61
60<Δ≦80	9.73	-2.29	0.986	54	750<Δ≦950	14.9	-2.46	0.989	49
80<Δ≦100	6.19	-1.50	0.980	54	950<Δ≦1150	10.9	-1.82	0.993	53
100<Δ≦120	5.81	-1.42	0.984	53	1150<Δ≦1350	10.7	-1.96	0.976	23
120<Δ≦140	5.18	-1.26	0.991	50	1350<Δ≦1550	11.6	-2.02	0.962	34
140<Δ≦160	5.73	-1.45	0.976	51	1550<Δ≦1750	8.61	-1.49	0.978	37
160<Δ≦180	5.56	-1.37	0.988	47	1750<Δ≦1950	8.25	-1.49	0.917	23
180<Δ≦200	5.72	-1.38	0.988	49					

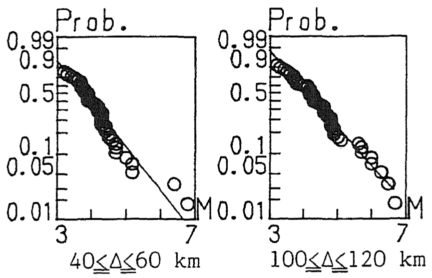


Fig.5 Extreme Value Distribution of Earthquake Magnitude taken into account of Epicentral Distance for Intra-plate Earthquake

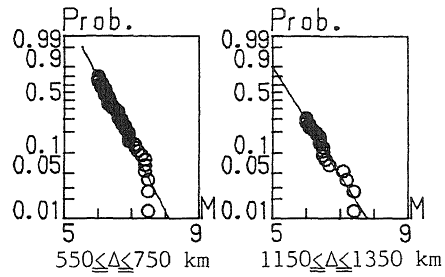
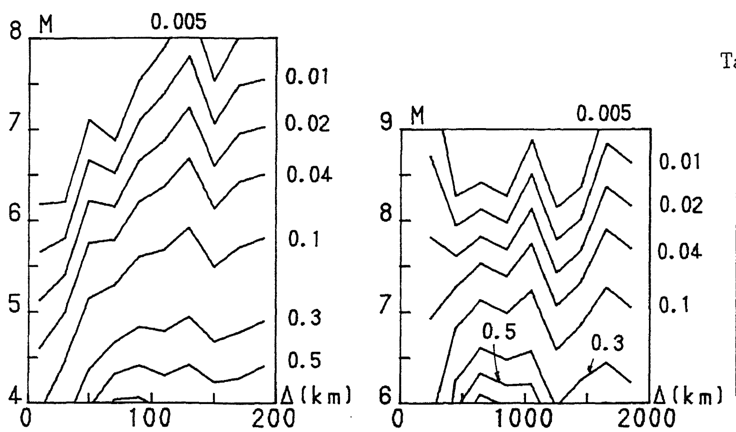


Fig.6 Extreme Value Distribution of Earthquake Magnitude taken into account of Epicentral Distance for Inter-plate Earthquake

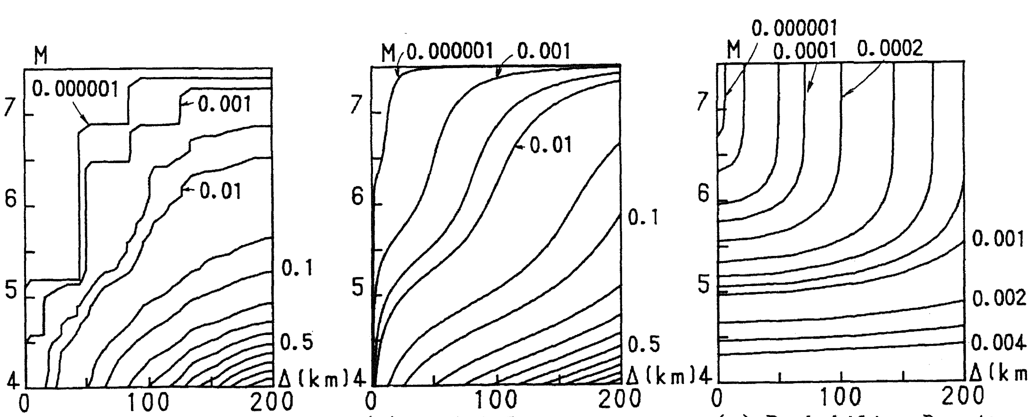


(a) Intra-plate Earthquake (b) Inter-plate Earthquake

Fig.7 Earthquake Occurrence Probability in M-Δ Plane using Extreme Value Distribution

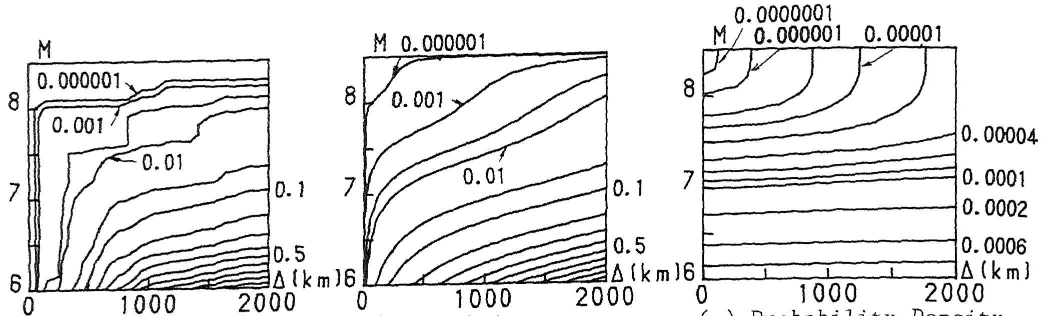
Table 4 Coefficents of Simultaneous Probability Distribution Function on Eq.(5)

Earthquake Types	Intra-plate Earthquake	Inter-plate Earthquake
M_l	4.0	6.0
M_s	7.5	8.5
Δ_s (km)	200	2000
a	$4.27x10^{-6}$	$2.43x10^{-5}$
b	$2.31x10^{-8}$	$7.91x10^{-12}$
k	6.0	4.0
r	0.975	0.989



(a) Observed Data (b) Probability Distribution (c) Probability Density Distribution

Fig.8 Simultaneous Probability Distribution in M-Δ Plane for Intra-plate Earthquake



(a) Observed Data (b) Probability Distribution (c) Probability Density Distribution

Fig.9 Simultaneous Probability Distribution in M-Δ Plane for Inter-palte Earthquake

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