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STATIONARY SEISMIC HAZARD IN JAPAN BASED ON THE SEISMOTECTONICS

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ABSTRACT

Stationary seismic hazard is necessary for the seismic design of structures and the prevention of seismic disasters. However, the seismic hazard derived directly from the earthquake catalogs depends strongly on their record period and reliability. To obtain the stationary hazard in Japan, the seismic risk analysis by the probabilistic method is used, which are based on the areal seismic source model derived from the seismotectonics and its occurrence parameters. The stationary seismic parameters of the model are determined as the most suitable values in four methods using three recurrence curves of the different period of two earthquake catalogs. The extreme value distributions of yearly maximum displacement and yearly maximum acceleration at several sites are calculated by this model and compare observed ones. The hazard map in and near Japan is made, which shows the acceleration of 100-year return period.

KEYWORDS

seismic hazard, seismic risk, hazard map, extreme value distribution, return period, earthquake catalog, areal source model, recurrence curve.

INTRODUCTION

Although many methods to analyze seismic hazard are proposed, the most reasonable and usable method is the probabilistic method that is based on some areal seismic sources of uniform occurrence of earthquakes and uses an attenuation curve. Then the reliability of seismic hazard by the probabilistic method depends on the properties of used sources. The configuration of seismic sources and their parameters of earthquake occurrence; b-value, the maximum magnitude and the rate of occurrence; are the most important, in particular.

Cornell (1968) proposed three seismic source models that are a point source, a line source and an areal source. The line source model is suitable for the model of active faults, but it is difficult to use it in Japan because the data of active faults are not sufficient in some metropolitan areas with deep alluvium. On the other hand, the areal source model can be applied to any regions in which active faults are known or not. So we use the areal seismic source model to analyze the seismic hazard in and near Japan.

If there is no information about the mechanism of earthquake occurrence, the uniform shape and size of the source may be chosen, such as the region of one degree by one degree. However, if we can use the information of seismotectonics and decide the configuration of sources to fit the information, more reliable seismic hazard will be obtained.

We propose an areal seismic source model in and near Japan, which is originally based on the division of the seismotectonics proposed by Hagiwara (1991) and is modified by the data of the location of active faults and earthquakes, and estimate the seismic parameters of the sources that reflect stationary occurrence by earthquake catalogs. Using the seismic risk analysis by the probabilistic method with the estimated parameters and Kanai's attenuation curve, the extreme value distributions of yearly maximum displacement and yearly maximum acceleration at several sites in Japan are calculated and are compared with observed ones. And the hazard map in and near Japan is made, which shows the acceleration of 100-year return period.

AREAL SOURCE MODEL

Hagiwara (1991) proposed the practical division of seismotectonics in and near Japan that is derived from many results by several researchers and the data of the locations of earthquakes and consists of about thirty regions covered four main islands. These regions are considered as the areal sources where the characteristics of earthquakes; such as b-value and the maximum magnitude; are constant. However, these regions are too large to consider that earthquakes occur uniformly in the region.

We propose the source model as shown in Fig. 1 that is composed from two types of sources; large size sources and small size sources. The division of large sources is originally based on Hagiwara's division, but some modifications are done to fit the configuration of active faults and the location of earthquakes and to cover the southwestern islands. Solid lines in Fig. 1 divide large sources where the b-value and the maximum magnitude are constant and dashed lines divide small sources where earthquakes uniformly occur. Figures in Fig.1 denote the number of a large source. The area of a small source is selected to almost 10^4(km^2) which corresponds to the aftershock area of magnitude M=8. The shapes of many small regions are trapezoids and some are triangles for the easiness of fitting the seismotectonics and the convenience of the analysis.

Fig. 2 shows the relation between the source model and the configuration of active faults, where some parts of faults under the sea are not shown by the lack of the data. Fig. 3 shows the relation between the source model and the location of earthquakes which are reported from 1985 to 1990 in magnitude greater than 5 and depth lower than 100 km by the catalogs described later. From these figures, the proposed source model is considered reasonable.

PARAMETERS OF EARTHQUAKE OCCURRENCE

First, we must decide the b-value, b, the maximum magnitude, m_1, and total occurrence rate greater than M=5 per year, $\Sigma\lambda$, of the large source regions using earthquake catalogs and the seismotectonics. The most serious problem using the catalogs is that their content and reliability change with time. Then, two earthquake catalogs are used in this analysis which are compiled by Utsu (1979) from 1885 to 1925 and by the meteorological agency from 1926 to 1990. Although they are considered the most reliable data, the greater part of the earthquakes of Utsu'catalog are of magnitude $M\geq6$ or destructive ones.

The maximum magnitude, m_1, of the sources are determined by considering the maximum magnitude of the catalogs or the magnitude estimated by the largest active fault in the large source. These values are shown in Fig. 4 or Table 1.

The b-value, b, and total occurrence rate, $\Sigma\lambda$, of large sources are estimated by the catalogs. To obtain the parameters which reflect stationary seismic activity, we divide the catalogs to three periods; (1)1885-1925, (2)1926-1950 and (3)1951-1990; in which the reliability of data is considered almost constant. After getting three recurrence curves in these periods, we estimate the values from four modified recurrence curves obtained by modifying three curves in four methods as follows.

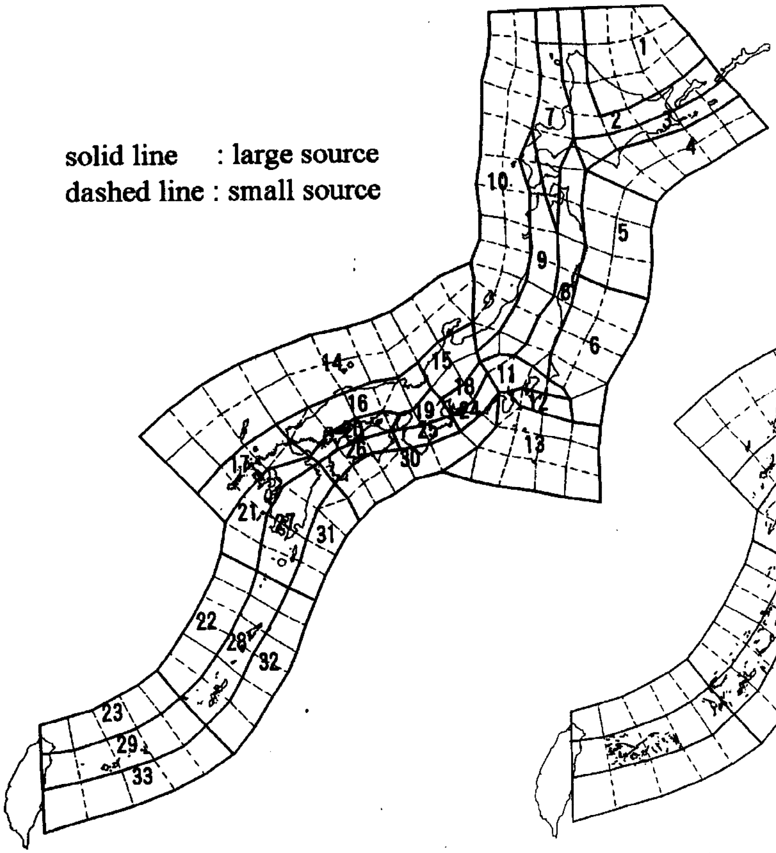


Fig. 1 Areal source model

Fig. 2 Relation between sources and active faults

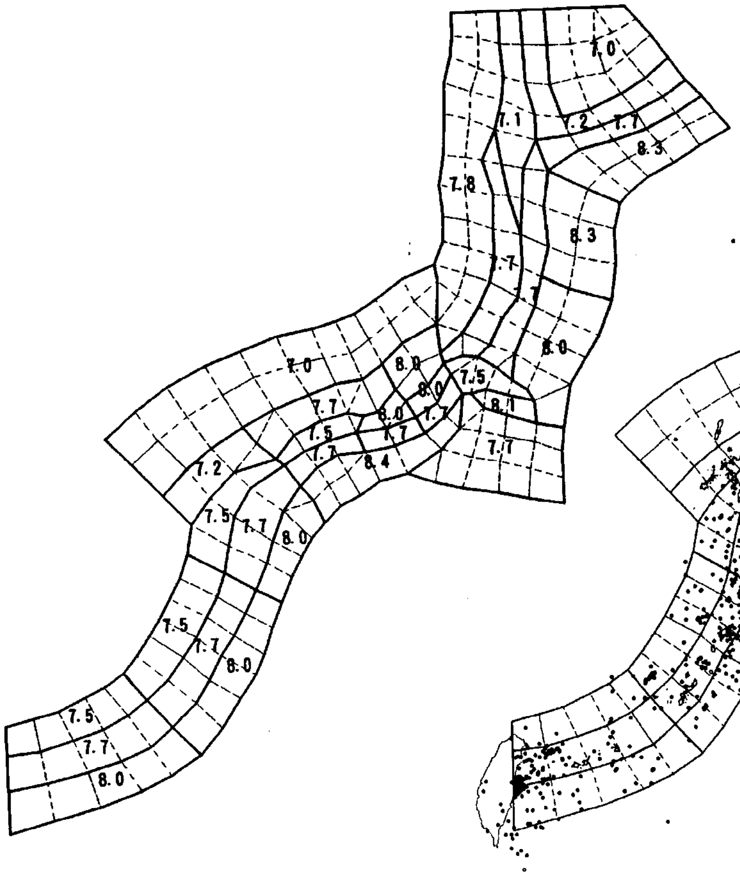


Fig. 4 The maximum magnitude, m_1

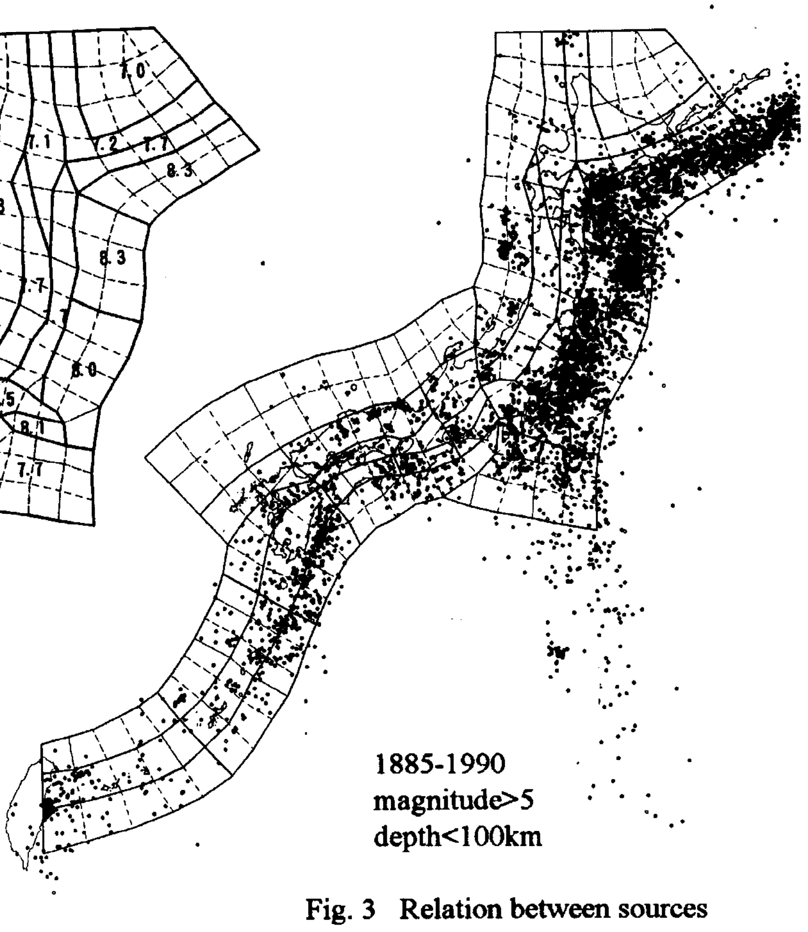


Fig. 3 Relation between sources and earthquakes

Method 1 :

$$Nr(m)=\frac{N1(m)+N2(m)+N3(m)}{3} \qquad 6<m \qquad (1)$$

$$Nr(m)=N3(m)*\frac{N1(6)+N2(6)+N3(6)}{3*N3(6)} \qquad 5<m\leq 6 \qquad (2)$$

where, $Nr(m)$, $N1(m)$, $N2(m)$ and $N3(m)$ represent the total number of magnitude greater than m, in the modified curve, the period case (1), the period case (2) and the period case (3), respectively.
The b-value is estimated by the likelihood method by the distribution $Nr(m)$ of $m\geq 5$.

Method 2 :

$$Nr(m)=\frac{N1(m)+N2(m)+N3(m)}{3} \qquad 6<m \qquad (3)$$

$$Nr(m)=\{N2(m)+N3(m)\}*\frac{N1(6)+N2(6)+N3(6)}{3*\{N2(6)+N3(6)\}} \qquad 5<m\leq 6 \qquad (4)$$

The b-value is estimated by the likelihood method by the distribution $Nr(m)$ of $m\geq 5$.

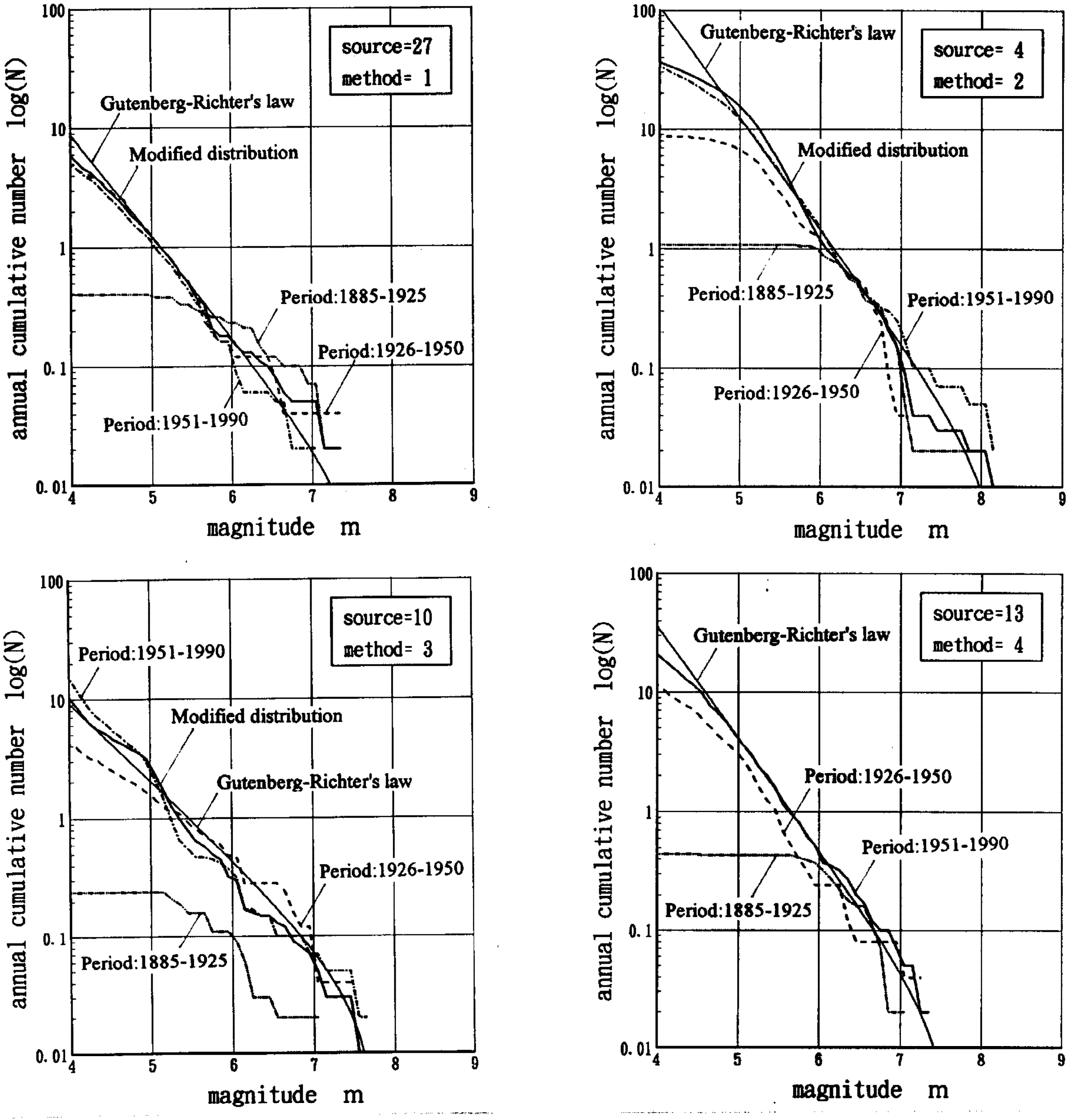


Fig. 5 Recurrence curves and estimated Gutenberg-Richter's law

Method 3 :

$$Nr(m)=\frac{N1(m)+N2(m)+N3(m)}{3} \qquad 6<m \qquad (5)$$

$$Nr(m)=\{N2(m)+N3(m)\}*\frac{N1(6)+N2(6)+N3(6)}{3*\{N2(6)+N3(6)\}} \qquad 5<m\le 6 \qquad (6)$$

$$Nr(m)=N3(m)*\frac{N1(5)+N2(5)+N3(5)}{1.5*\{N2(5)+N3(5)\}} \qquad 4<m\le 5 \qquad (7)$$

The b-value is estimated by the likelihood method by the distribution Nr(m) of $m\ge 4.5$.

Method 4 :

The b-value is estimated by the likelihood method by the distribution Nr(m)=N3(m) of $m\ge 5$.

The total occurrence rate, $\Sigma\lambda$, which is greater than magnitude 5 per year, are determined as the mean of two values, with which the Gutenberg-Richter law fits the modified recurrence curve, at m=5 and m=6. Examples of the recurrence curves for four methods are shown in Fig. 5. The most appropriate values of b and $\Sigma\lambda$, which are considered stationary values, are selected from the values which give the best fitness between the modified recurrence curves and the Gutenberg-Richter law with the estimated values. Generally, the method 1 or 2 is adapted in the region that earthquakes occurred. On the other hand, the method 3 or 4 can be adapted in the region that earthquakes are many earthquakes occurred. On the other hand, the method 3 or 4 can be adapted in the region that earthquakes are scarce or old catalog are not used. The results are shown in Fig. 6 and Table 1. The symbol of $\Sigma\lambda/A$ in the table shows the occurrence rate per the area of $10^4(km^2)$ for easy to compare the seismic activity.

The occurrence rates of the small regions, λ, are obtained from $\Sigma\lambda$ of a large region by proportionally distributing to the occurrence of m>5 in each small region. The estimated values of λ are shown in Fig. 7. Although λs of some small sources are zero and this is not true for a long period, no correction is done in this analysis.

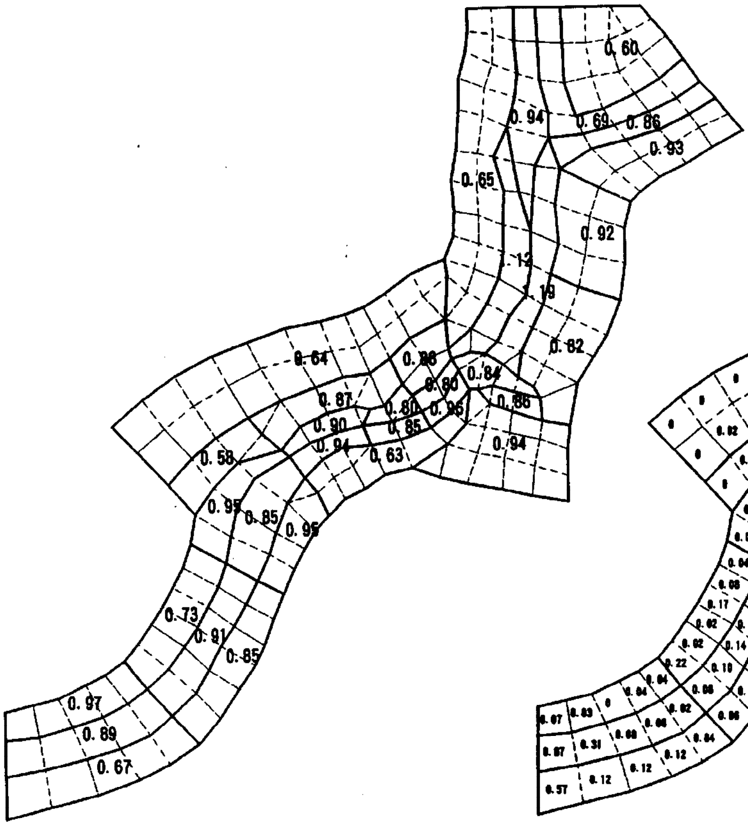


Fig. 6 b-value, b

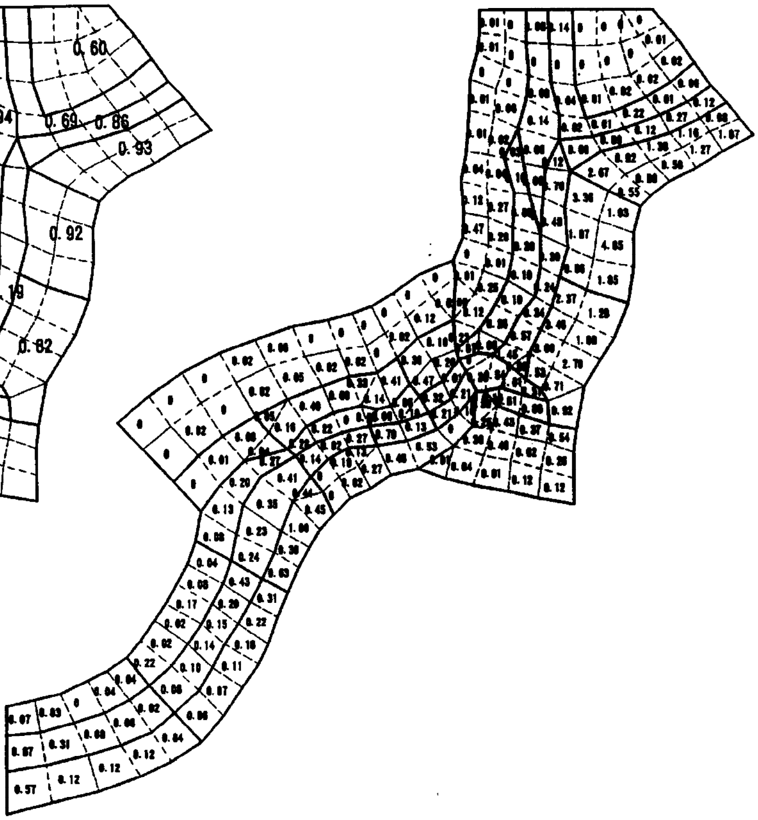
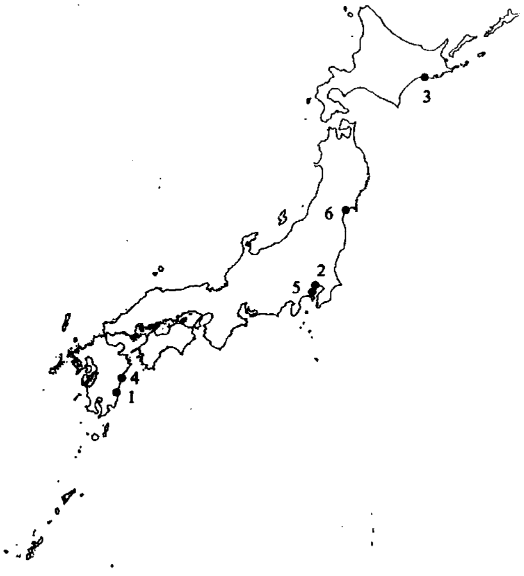


Fig. 7 Occurrence rate, λ ,
of m>5 of small source

Table 1 Seismic occurrence parameters

source number	m_1	selected method	modifying & fitting	b-value b	rate $\Sigma\lambda$	$\Sigma\lambda/A$ (10^4km^2)
1	7.0	1	good	0.597	0.070	0.008
2	7.2	2	very good	0.686	0.504	0.084
3	7.7	2	very good	0.862	1.214	0.358
4	8.3	2	very good	0.934	12.271	1.654
5	8.3	4	very good	0.917	14.518	1.905
6	8.0	1	very good	0.823	17.759	1.950
7	7.1	2	good	0.942	0.409	0.080
8	7.7	2	very good	1.188	5.088	0.883
9	7.7	2	good	1.119	1.798	0.300
10	7.8	3	good	0.647	2.014	0.123
11	7.5	1	good	0.843	2.419	1.102
12	8.1	2	very good	0.858	1.782	1.350
13	7.7	4	very good	0.938	4.081	0.364
14	7.0	1	very good	0.637	0.366	0.014
15	8.0	2	very good	0.877	1.184	0.399
16	7.7	2	very good	0.870	2.185	0.388
17	7.2	3	bad	0.582	0.137	0.030
18	8.0	3	good	0.800	0.336	0.321
19	8.0	3	good	0.796	0.222	0.172
20	7.5	2	very good	0.899	0.529	0.271
21	7.5	1	very good	0.950	0.667	0.152
22	7.5	4	very good	0.729	0.549	0.081
23	7.5	4	bad	0.974	0.184	0.031
24	7.7	2	good	0.960	0.426	0.397
25	7.7	2	very good	0.849	0.916	0.665
26	7.7	3	very good	0.938	0.439	0.247
27	7.7	1	very good	0.846	1.233	0.220
28	7.7	2	very good	0.912	1.095	0.172
29	7.7	2	good	0.888	1.333	0.181
30	8.4	2	good	0.632	1.627	0.246
31	8.0	1	very good	0.952	2.905	0.705
32	8.0	1	very good	0.854	0.948	0.130
33	8.0	4	good	0.670	0.978	0.108



Displacement sites
(JMA observatories)
1. Miyazaki
2. Tokyo
3. Kushiro
Acceleration sites
(SMAC accelerometer)
4. Hosojima
5. Yokohama
6. Shiogama

Fig. 8 Location of sites in Figs. 9 and 10

DISTRIBUTION OF ANNUAL MAXIMUM DISPLACEMENT

The extreme value distributions of the annual maximum displacement are analyzed by the probabilistic method using the areal seismic sources with the estimated parameters to compare the distributions which are observed at the Japan meteorological observatories. Fig. 9 shows three observed distributions at Miyazaki, Tokyo and Kushiro in Fig. 8, which are observed from 1951 to 1990 and are plotted by circles using the Hazen plotting position. Asterisks denote estimated values by the catalog because of the lack of observed data.

The attenuation curve is used which is derived from Kanai's relation (1969) and is modified a little as follows,

$$y=c_1*10^{\{m-(1.66+3.60/x)\log(x)-3.13-1.83/x\}} \qquad (8)$$

where, y, m, x, c_1 denote the peak ground displacement (cm), the magnitude, the hypocentral distance (km) and a correction factor by soil effect, respectively.

The distribution of the scatter of the attenuation curve is assumed to be the logarithmic normal distribution with the coefficient of variation of 0.6. The small regions within 300 km from the site are considered in the analysis and the depth of earthquakes is assumed to be 30 (km) and constant.

Although the analyzed distributions do not completely fit the observed distributions because of the short period of the observation, they have the same characteristics. Other results for eleven sites which are not shown in this paper show the same good agreement.

DISTRIBUTION OF ANNUAL MAXIMUM ACCELERATION

The extreme value distributions of annual maximum acceleration are analyzed in the same manner to compare the distributions which are observed on the ground at ports by the SMAC accelerometers. Fig. 10 shows three observed distributions at Hosojima, Yokohama and Shiogama, which are observed from about 1965 to 1990 and are plotted by circles using the Hazen plotting position.

The attenuation curve is used which is proposed by Kanai (1969) with the natural period of the soil of 0.6 (sec) which is corresponded to the second class (moderate) soil in the Japanese seismic code.

$$y=6.45*10^{\{0.61m-(1.66+3.60/x)\log(x)+0.167-1.83/x\}} \qquad (9)$$

where, y denotes the peak ground acceleration (cm/s²).
Other assumptions are the same as the displacement.

The analyzed distributions do not somewhat fit the observed distributions in comparison with the displacement because the period of the observation is very short and the analysis does not considere the soil effect. However, they show the same characteristics except for the size which might depend on the soil condition. Other results for four sites which are not shown in this paper show the same relation.

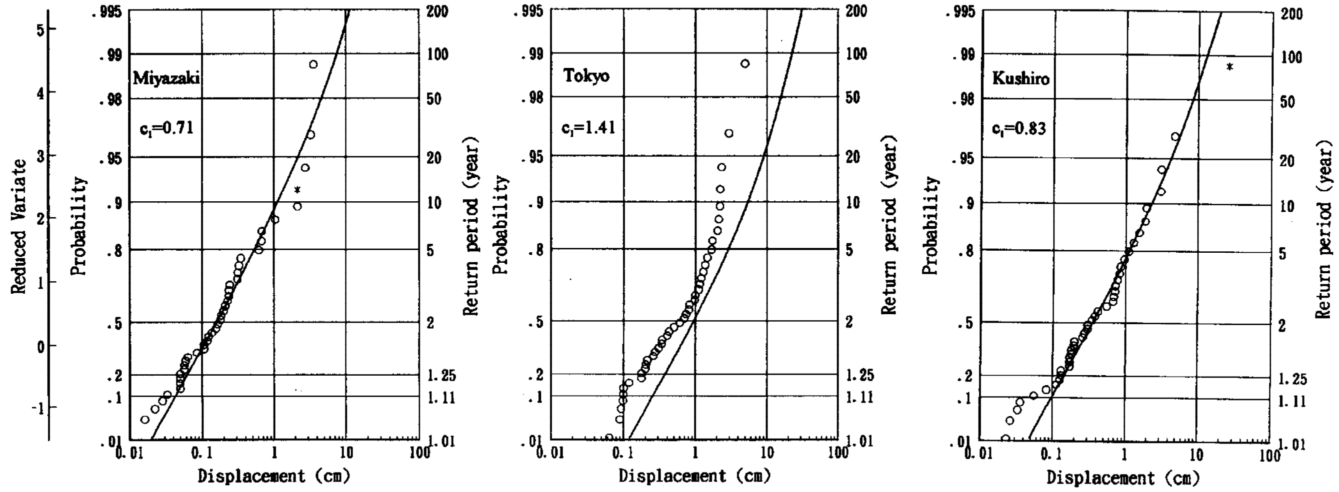


Fig. 9 Extreme value distributions of yearly maximum displacement
(Circles denote observed values and asterisks denote estimated values)

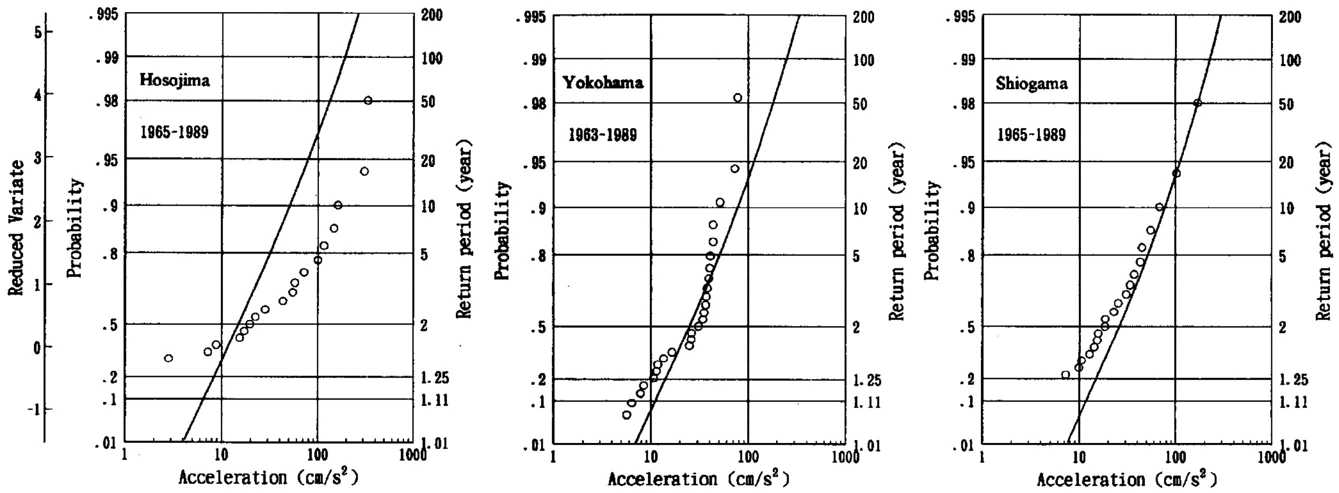


Fig. 10 Extreme value distributions of yearly maximum acceleration

SEISMIC HAZARD MAP

The extreme value distributions of annual maximum acceleration are analyzed in the same procedure at 0.5-degree mesh points in latitude and longitude to obtain a seismic hazard map in and near Japan. The 100-year return period values are shown in Fig. 11 and the contour lines of 50, 100, 200 and 400 (cm/s^2) are shown too.

The most hazardous regions are on the coast of Pacific ocean which are near the subduction zones along the Japan trench and the Nankai trough. On the other hand, the regions of lower degree of hazard are the northern part and the western part. Although the ratio of lower values to upper values is about 1/4, that of the code is 0.8 except the special case of Okinawa prefecture. The distinctive result in this analysis is that the return period values which adjoin each other do not drastically change unlike ever proposed maps. This shows that this procedure is more reliable and stationary.

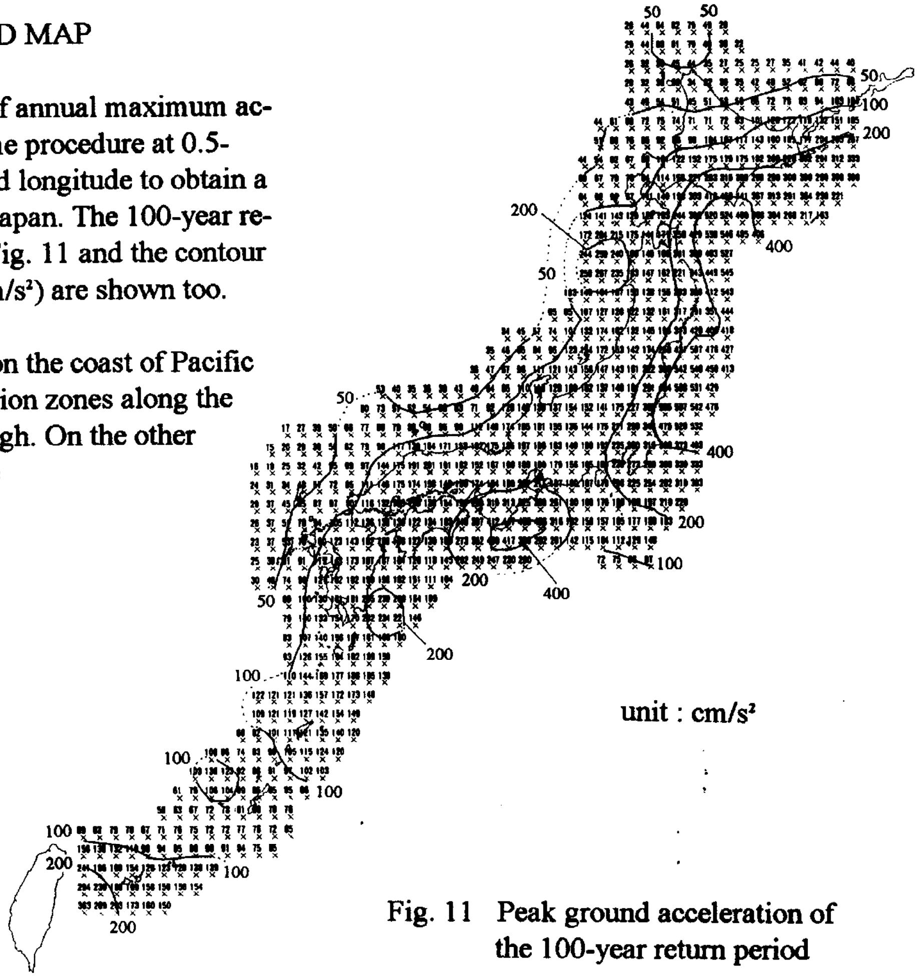


Fig. 11 Peak ground acceleration of the 100-year return period

CONCLUSIONS

The probabilistic method to analyze stationary seismic hazard is proposed, which use areal seismic sources based on the seismotectonis and stationary parameters estimated by the modified recurrence curve of earthquake catalogs. The extreme value distributions of annual maximum displacement using this model are in good agreement with the observed ones obtained in the Japan meteorological observatories. The extreme value distributions of annual maximum acceleration using this model show the same characteristic with the observed ones in the port sites. The seismic hazard map of the acceleration of 100-year return period in and near Japan is obtained using this model and it shows that this model reflects stationary seismic activity.

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