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

2-1-9

SEISMIC HAZARD ESTIMATION BASED ON EARTHQUAKE RECURRENCE RATE IN COMPARISON WITH EMPIRICAL EXTREME VALUE DISTRIBUTION

Jun KANDA[1],Ryoji IWASAKI[1],Yoshio KITADA[2]

Hiroshi NAKAMIZO[2],Masaaki OGATA[3]

1) Department of Architecture, University of Tokyo, Tokyo, Japan
2) NAIG Nuclear Lab., Nippon Atomic Industry Group Co., Kawasaki, Japan.
3) Nuclear Energy Division, Toshiba Corporation, Yokohama, Japan

SUMMARY

A basic study on the seismic hazard estimation, based on the method proposed by Cornell, was carried out through application to a site in Tokyo area. The Gutenberg-Richter equation, which expresses the relation between recurrence rate for earthquakes and earthquake magnitude, was truncated by fitting historical earthquake data in the larger magnitude range, in order to make realistic recurrence rate estimation. The effect of variation in the attenuation law, for earthquake ground motion, on the estimated seismic hazard was also investigated. The comparison between resultant seismic hazard and seismic hazard, estimated by Kanda et al., which was accomplished using a different method, shows good correspondence.

INTRODUCTION

Recently, many seismic hazard estimation have been implimented as an important part of the probabilistic seismic safety analysis for nuclear power plants. As a result of sensitivity study on the current seismic hazard estimation method, it is pointed out that the earthquake recurrence rate and the attenuation law for the ground motion have considerable effects on the resultant seismic hazard. Particularly the coefficient of variation (c.o.v.), which stands for the uncertainty in the equation for earthquake ground motion attenuation, was reported to be one of the most important parameters for seismic hazard analyses (Ref.1). The present study was made to find a realistic seismic hazard analysis method, through seismic hazard estimation for a site in the Tokyo area. The method used in this study was due to McGuire (Ref.2), based on a seismic hazard estimation method proposed by Cornell (Ref.3). In this study, first, the variation effect in the attenuation estimation on the resultant seismic hazard was investigated. Second, a comparison was carried out on a resultant seismic hazard concerning those estimated by Kanda et al.(Ref.4), based on an empirical extreme value distribution.

ESTIMATION METHOD AND NUMERICAL EXAMPLE

As a numerical example, a site was assumed in the Tokyo area. For this site, a surrounding square region, 300 kilometers on a side, was postulated as a seismic source zone. The zone consists of nine sub-regions. These are one central sub-region, which covers the site and eight sub-regions, which surround the central. The geometry of the site and the seismic sub-regions is shown in Fig.1. The annual earthquake recurrence rate for each seismic sub-region was estimated by referring to the historical destructive earthquake data edited by

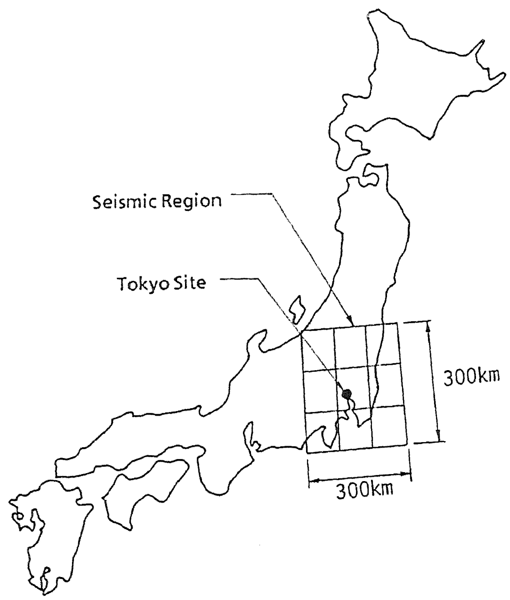

Fig. 1 Site Location and Seismic Region

Table 1 Analytical Conditions of Each Sub-Region

① 0.465*1 ② 0.057 ③ 7.5 ④ 24.0	1.505 1.531 7.5 30.0	0.467 0.106 7.5 35.0
0.561 0.170 7.5 30.9	0.738 0.404 7.5 52.5	0.665 0.121 8.6 30.0
0.467 0.428 8.6 27.2	0.686 0.443 8.6 31.0	(no data)

NOTE: The locations of each sub-seismic source region have one-to-one correspondence to those shown in Fig.1.

*1 Four figures in each column are as follows:
① b-value in the Gutenberg-Richter Formula
② Annual Recurrence Rate of Earthquakes (Earthquake Magnitude greater than 5.0)
③ Upper Limit Magnitude
④ Estimated Focal Depth (km)

Usami (Ref.5). The period taken into consideration in this study covers 85 years (1900–1984), since the data in this period was considered to be consistently reliable. Analytical conditions for each sub-region are shown in Table 1. The upper limit in the earthquake magnitude for each seismic sub-region was assumed from the historical earthquake data with some margins, as 8.6 on the Richter scale or marine sub-regions and 7.5 on the same scale for inland sub-regions. The lower limit of earthquake magnitude was assumed for all sub-regions as 5.0. Earthquakes, whose magnitude is less than 5.0, were considered to be ineffective in the engineering sense. Earthquake recurrence rate in each sub-region was expressed by fitting the following Eq.(1) from the Gutenberg-Richter (G-R) formula to historical earthquake data.

$$\log n = a - b\,m \tag{1}$$

Where n is the number of earthquakes having greater magnitude than m. Coefficients a and b are constants determined for each seismic source sub-region. The b-value describes the relative distribution of small and large-magnitude earthquakes. Although, in general, the number of the earthquakes follows the G-R formula to a certain magnitude, the number tends to be markedly lower than that estimated by the G-R formula in the larger earthquake magnitude range. Then, the further truncation of the G-R formula was introduced by applying the following equation in the larger magnitude range. A quadratic equation was applied to the probability density form of the G-R formula ;

$$f(m) = -p\cdot m^2 + q\cdot m + r$$

$$p = (a - m_t + k_t)/(m_1 - m_t)^2$$

$$q = (2a\cdot m_t - b(m_1^2+m_t^2) - 2k_t\cdot m_t)/(m_1 - m_t)^2 \tag{2}$$

$$r = (m_1(m_1 - 2m_t)a + b\cdot m_t^2\cdot m_1 + m_t^2\cdot k_t)/(m_1 - m_t)^2$$

where m_1 is the upper limit earthquake magnitude to be considered, m_t is the beginning earthquake magnitude of truncation, and k_t is the value of the probability density at $m = m_1$. An example for fitting the G-R formula with Eq.(2) is shown in Fig.2.

In the present study, the following attenuation law, proposed by Kanai, was substituted for the original law (Ref.2), in order to read out consistency with Japanese earthquake data ;

$$v = 10^{-(0.631+1.83/x)+0.61m-(1.66+3.6/x)\log(x)} \qquad (3)$$

v : Peak ground motion velocity
x : Distance to hypocenter

In the application, the peak acceleration was obtained by multiplying the v value in Eq.(3) by a factor 14. The factor was determined by considering a typical stiff soil site having natural period of 0.45 second. Figure 3 shows the annual exceedance probability (AEP) for the ground acceleration, according to the model shown in Fig.1. Among seismic sub-regions considered, the region south-west from the central and the sub-region south of the central have dominant effects on the total seismic hazard at the site. In this figure, three cases of seismic hazard estimation results are shown. For the first case, the G-R formula was directly applied. For the second case, the G-R formula was truncated to fit historical data, where m was greater than 8.0. For the third case, the G-R formula was truncated to fit historical data where m was greater 7.0. It should be noted that modification to the G-R formula (Eq.(1)) has considerable effects on the seismic hazard estimation.

The the c.o.v. effect in the attenuation law to the seismic hazard estimation was investigated, based on the assumption that the earthquake attenuation data has lognormal distribution around the attenuation equation. The

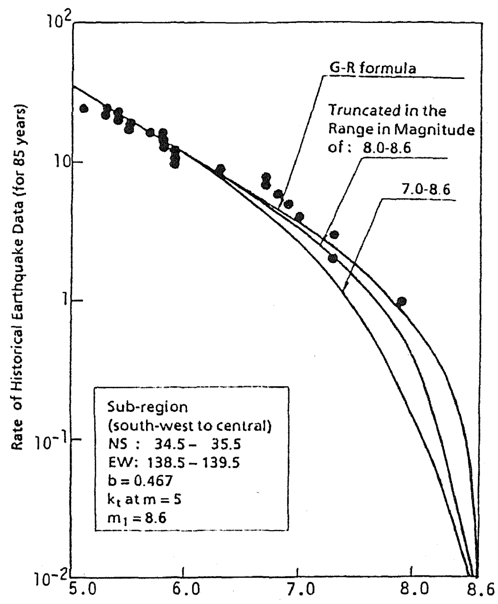

Fig. 2 An Example of Truncation in Gutenberg-Richter Relation and Distribution of the number of the Historical Earthquake data to Magnitude

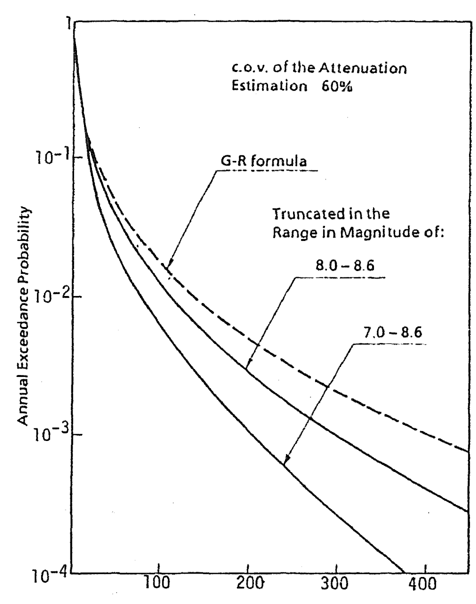

Fig. 3 Annual Exceedance Probability of the Acceleration of the Earthquake Ground Motion

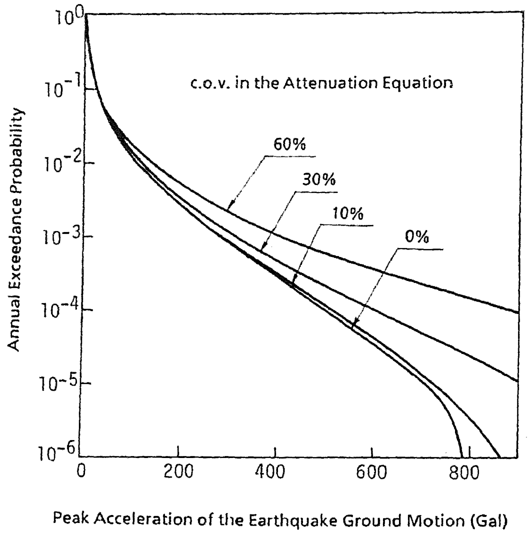

Fig. 4 Seismic Hazard Curves Estimated with Different c.o.v. in the Attenuation Equation on the Acceleration of the Earthquake Ground Motion

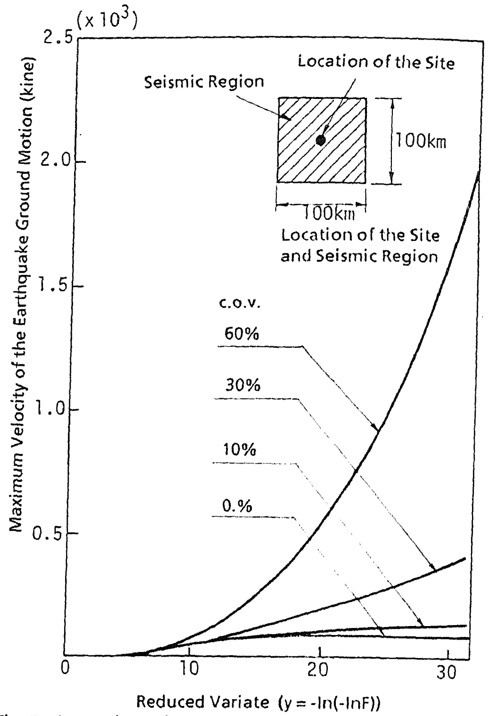

Fig. 5 Comparison of the Maximum Earthquake Ground Motion Velocity Curves Estimated by Varying C.o.v. in the Attenuation Estimation

b-value	1.0
Magnitude Range	5.0 – 8.6
Focal Depth	30. (km)

c.o.v. range varied from 0 % to 60 %, where the G-R formula was used without the truncation of Eq.(2). Estimated seismic hazards are shown in Fig.4. From this figure, it can be seen that the AEP for the ground motion, in the 60 % c.o.v. case, is considerably greater than for the 0 % c.o.v. case, and the difference expands as the peak acceleration increases. The decrease in AEP against the peak acceleration for the 60 % c.o.v. case becomes insignificant in the greater acceleration range.

The double exponential form has often been used as an appropriate form for distribution function indicating extreme values which are assumed to be independent statistically and expressed by the stochastic processes. The c.o.v. effect in attenuation law on the seismic hazard estimation was expressed on double exponential probability paper as shown in Fig.5. In the figure, the ordinate is the maximum velocity for the earthquake ground motion v, and the abscissa is reduced variate y, where $y = -\ln(-\ln F)$, and F is the annual non-exceedance probability, i.e. F = 1.0 – AEP. The figure shows four cases of estimated maximum velocity curves, with the c.o.v. in the attenuation law as a parameter. This figure indicates that the larger the c.o.v. value in the attenuation law becomes, the more significance there is for larger reduced variate. The maximum velocity for the 60 % c.o.v. is three times greater than that for the 0 % c.o.v., when reduced variate y = 14, which corresponds to the annual exceedance probability of 10-6. Moreover, although some upper limits can be recognized for cases having smaller c.o.v. in the ground motion attenuation, such as 0 % or 10 %, the existence of the upper limit can hardly be pointed out for the cases having greater c.o.v., such as 30 % or 60 %, as recognized in Figs.4 and 5.

COMPARISON WITH EMPIRICAL EXTREME VALUE DISTRIBUTION

In order to obtain better understanding for the seismic hazard estimation method, a comparison was carried out for the seismic hazard, estimated by the present method, with that estimated in another study. The study performed by Kanda et al. (Ref.4) was used as a reference case. In their study, the maximum velocities due to the earthquake were estimated for several cities in Japan, through the statistical investigation on the historical earthquake data. The data used in their study were also sampled basically from the data on destructive earthquakes edited by Usami. The sampling period for these data was 300 years (1681–1980), while that of the present study is 85 years. The procedure for estimating annual exceedance probability of earthquake velocities from the 300-year data was as follows. First, the annual maximum earthquake velocities at the site were evaluated for the 300-year range in the historical earthquake data. Second, the annual maximum velocity values were sorted in descending order. Then, the non-exceedance probability of the j-th velocity value, Fj, was defined by using the order number, j, as follows ;

$$F_j = 1 - (j - 0.5)/T \qquad (4)$$

where T is the the total sampling period in year for the earthquake data. Kanda et al. proposed the form of the extreme value distribution function of earthquake velocity, which was defined to express the relation between evaluated annual maximum velocities and the non-exceedance probability of the earthquake

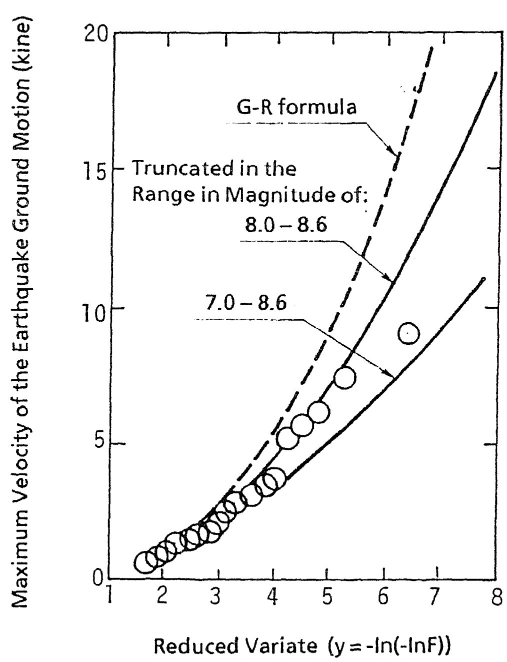

Fig. 6 Comparison of Maximum Velocity Distribution of the Earthquake Ground Motion Estimated by the Present Method and that Estimated by Kanda et al

A 0% of c.o.v. in the Attenuation Equation was used.

velocities. In this process, annual non-exceedance probability values for the maximum earthquake ground motion velocities were plotted on the double exponential probability paper.

A comparison is made between the annual non-exceedance probabilities for earthquake ground motion velocities, for the site shown in Fig.1, estimated by the present method with varying truncation tendencies and 0 % c.o.v. for the earthquake ground motion attenuation law, and those estimated by Kanda et al. The comparison result is shown in Fig.6. The circles in the figure represent the results obtained by Kanda et al.. The solid lines and the dashed line in the figure represent the results obtained in the present study. The dashed line, which corresponds to the case based on the G-R formula fitted to the historical earthquake data, seems to be a slight over estimation. The cases indicated by solid lines, in which the G-R formulas were truncated by fitting historical earthquake data using Eq.(2), show good correspondence with the circles in the figure. When a large c.o.v. value for the attenuation estimation, say 60 %, is applied, further overestimation in regard to the seismic hazard seems to be dominant especially in a large reduced variate range in comparison with the previous seismic hazard study (Ref.4).

CONCLUSION

A fundamental study on the probabilistic seismic hazard estimation method developed by Cornell was carried out through the seismic hazard estimation for a site in the Tokyo area, using historical earthquake data. As a result of the investigation, the following conclusions may be drawn ;

(1) An alternative form for the further truncation from the G-R formula in the large magnitude range may be applied to the seismic hazard estimation.

(2) The seismic hazard computed with a large c.o.v. in the earthquake ground motion attenuation might lead to a fairly conservative estimation.

(3) Comparison between the seismic hazard, estimated by the present method, with that estimated by Kanda et al. was made. Both results are in good agreement, when a further truncation for G-R formula and a fairly low c.o.v. in the attenuation estimation are adopted.

REFERENCES

(1) Fukushima,Y.,et al., "Seismic risk assessment of high-rise building", Summaries of technical papers of annual meeting, Vol.I,pp.90-91, Architectural Institute of Japan ,1985 (in Japanese).

(2) McGuire,R.K., "FORTRAN Computer program for Seismic Risk Analysis", U.S.G.S., 1976.

(3) Cornell,C.A., "Engineering Seismic Risk Analysis", Bull.Seis.Soc.of America, Vol.58, pp.1583-1606, 1968.

(4) Kanda,J., et al, "Distribution of Seismic Hazard in Japan based on an Empirical Extreme Value Distribution", Structural Safety, Vol.4, pp.229-239, 1987.

(5) Usami,T., "Materials for Comprehensive List of Destructive Earthquakes in Japan", Univ. Tokyo Press, 1987 (in Japanese)