A Study on the Use of Seismic Data in the Seismic Hazard Estimation of PRA

Mamoru Mizutani, Takashi Kamiyoshihara
Tokyo Electric Power Services Company, Ltd., Tokyo, Japan
Masayuki Takemura, Hiroshi Ishida
Kajima Corporation, Tokyo, Japan

INTRODUCTION

In the estimation of seismic hazard in the PRA procedures, an inevitable uncertainty is involved and part of the uncertainty comes from the choice of the seismic data. As for the seismic source modeling, two approaches may be used. One is the use of the historical earthquake data and the other is the use of the understandings of characteristics of active faults.

The historical earthquake data give us the information of experienced earthquakes in the form of description and of instrumental record. The descriptions about destructive earthquakes have remained since A.D.416 in Japan (Usami et al. 1975), while the instrumental records have been obtained for recent 100 years. The effective period of the historical earthquake data is not long enough for the modeling of earthquake occurrence with long recurrence time.

On the other hand, the active fault data inform us seismic activities over a relatively long period. However, detailed surveys for the active faults are limited to inland and shallow part in the crust. We can get the information only about seismic activities of shallow earthquakes occurring inland. For that reason or not, the corresponding active fault to each historical earthquake has not been fully identified.

Thus, the historical earthquake data and the active fault data are not compatible nor complemental to each other. It is difficult, therefore, to develop a method for evaluating seismic hazard which smoothly integrates the information derived from both data.

In this study, we develop the seismic hazard estimation methods based on the historical earthquake data and on the active fault data separately. The applicability of them is discussed through the comparison of the seismic hazard curves estimated by these methods.

METHOD

On Historical Earthquake Data

The basic flowchart of seismic hazard estimation based on the historical earthquake data is illustrated in Figure 1. The seismic hazard curve is evaluated on the assumption of a Poisson's process from the annual mean number $\nu(a)$ of events that peak ground acceleration A_{max} exceeds a value of a at the site of evaluation. Here, $\nu(a)$ is calculated from the frequency-magnitude relationship by Gutenberg and Richter (G-R relation) for each seismotectonic zone around the site with an attenuation relationship for the peak ground acceleration. The procedures of this method have newly developed based on the PRA Procedures Guide (ANN/IEEE, 1983). The authors had also applied this method to estimate the spectral shapes dependent on the peak ground accelerations (Takemura et at., 1989), and Ishida et al. (1986) had used this method for the evaluation of the seismic intensity instead of the peak ground acceleration and showed the validity of the method through the comparison of the annual mean number with the seismic intensity data observed by the Japanese Meteorological Agency.

One of the most important procedures in this method is the determination of the coefficients *a* and *b* of the G-R relation. For large earthquakes as $M>7$, the historical earthquake data accumulated in Japan after Seventeenth Century are generally reliable, while for relatively small events as $5.5<M<7$ the data since 1885 are applicable. The G-R relation must be adjusted by the data of historical earthquakes since 1885, because the data of small earthquakes are also necessary for the precise evaluation.

For another important parameter, the maximum possible magnitude M_{max} of earthquakes in each seismotectonic zone, has to be determined referring to all the historical earthquake data since A.D.416 in consideration of the tectonic implications of the zone.

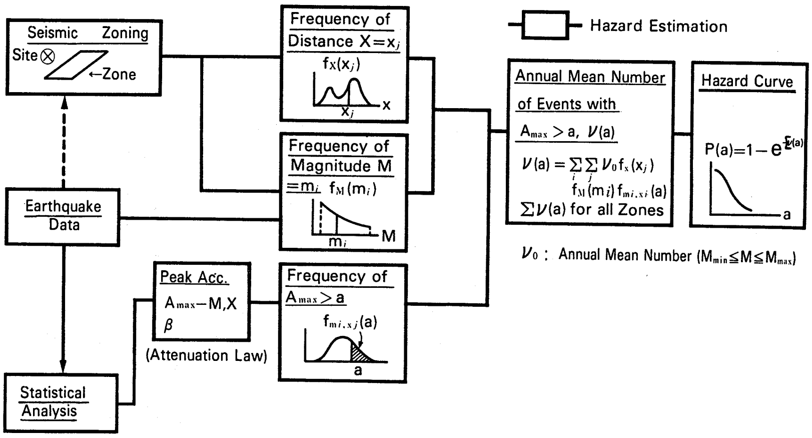

Figure 1. Seismic Hazard Estimation Method Based on Historical Earthquake Data

On Active Fault Data

Figure 2 shows the flowchart based on the active fault data. The data usually indicate the location of faults, fault length, activity of the fault, identification reliability of the fault, and so on (Univ. of Tokyo Press, 1980). The active faults are classified into several groups according to the annual mean slippage.

In the seismic hazard estimation method, the annual mean number $v(a)$ of the event, $A_{max}>a$, is evaluated from recurrence time of the earthquakes on the active faults around the site with an attenuation relationship. The recurrence time T of the earthquake is calculated using the relation of $T=d/s$, in which s shows the annual slip rate and d the slippage for each active fault. The slippage on the fault plane due to the earthquake is estimated by an empirical relationship to the magnitude M of the earthquake on the fault.

Kameda and Okumura (1985) and Tomatsu et al. (1983) have developed some different methods for evaluating seismic hazard curves based on the active fault data. They assumed the G-R relation satisfies the frequency-magnitude relation of earthquakes occurring along each fault. While, Wesnousky et al. (1983) indicated through the comparison with active fault data and historical earthquake data that the strain energy is released from an active fault mainly by the largest earthquakes of which magnitude is calculated from the fault length L. This results indicate a contradiction to the assumption of the G-R relation for each fault.

Therefore, we assume in the proposed method based on the active fault data that for each active fault M is defined uniquely by the fault length, and understand that the G-R relation explains the frequency-magnitude relationship of earthquakes in a wide region including various kinds of active faults.

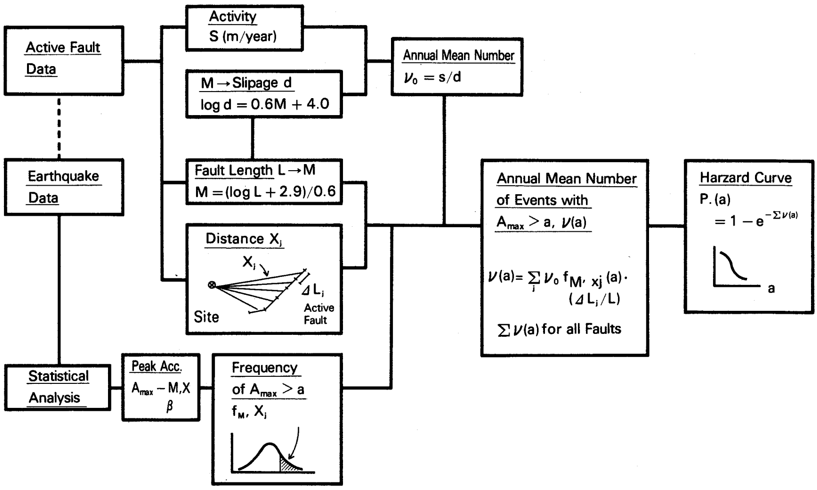

Figure 2. Seismic Hazard Estimation Method Based on Active Fault Data

Attenuation Relationship

The attenuation curve for the peak ground acceleration, A_{max}, used in both methods, on the historical earthquake data and on active fault data, is Kanai's empirical relation (Kanai, 1966) as follows;

$$A_{max} = \frac{1}{T_g} 10^{0.61M - (1.66 + 3.60/X)\log X + 0.167 - 1.83/X}$$

where X is hypocentral distance in *km* and T_g is a dominant period of seismic waves. T_g is estimated from magnitude M of the earthquake by using the T_g-M relation by Seed et al. (1969). The Kanai's relation is derived from observed seismograms on the rock site. Therefore, the hazard curves estimated in this study are corresponding to those at the rock site. The applicability of the relationship has been examined using recently recorded data in Japan and it confirms that the formula gives good estimation for the median relation, with logarithmic standard deviation *0.7*.

SEISMICITY AROUND THE SITES

The proposed methods are applied to the hazard estimation at Odawara and Kyoto, old capitals in Japan. Many descriptions have remained on earthquakes around these cities. Figure 3 shows the locations of these cities, and tectonics in and around Japan.

Near Odawara, the great Kwanto earthquake ($M = 7.9$) occurred in 1923, which killed 160,000 people. The occurrence of this earthquake was caused by the subduction of the Philippine Sea Plate along the Sagami Trough beneath the Honshu Island. The recurrence time of the great earthquakes of $M = 8$ class is *400* to *700* years along the Sagami trough. Another active seismic region around Odawara is in Philippine Sea Plate along

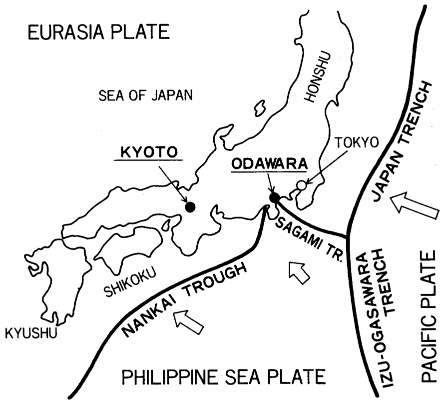

Figure 3. Tectonics in and around Japan

Izu Peninsula. The crust is swarming with frequent earthquakes of $M=6$ to 7. We can find that the seismic activity is very high around Odawara and that active seismic regions are mostly located under the sea.

On the other hand, seismic activity is not so high around Kyoto. Kyoto is at a distance from the subduction region along the Nankai Trough, where great earthquakes of $M=8$ class have repeated regularly with the recurrence time of about *100* years. The inland earthquakes caused by the active faults in the shallow part of the crust have given larger damage to Kyoto.

Figure 4 shows seismotectonic zones around Odawara and Kyoto, which are determined based on the distributions of historical earthquakes and .tectonics, also referring the the results of micro earthquake observation. We assume all earthquakes in each seismotectonic zone occur on a plane randomly for the calculation of the seismic hazard curve by the method based on the historical earthquake data. In this figure, M_{max} is the maximum magnitude of earthquakes in the zone, b is the b-value of the G-R relation, and ν_0 is the annual mean number of the events of $M>5$ estimated for each seismotectonic zone.

The active faults considered in the seismic hazard analysis are those indicated in "Active Faults in Japan" (Univ. of Tokyo Press, 1980) in the inland regions within 150 km from Odawara and Kyoto. In this study, 231 and 372 active faults are identified around Odawara and Kyoto respectively.

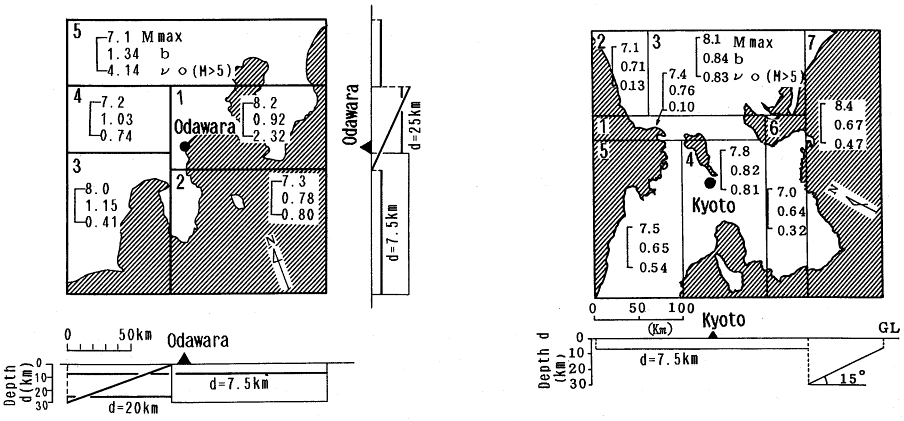

Figure 4. Seismotectonic Zones

RESULTS

On Historical Earthquake

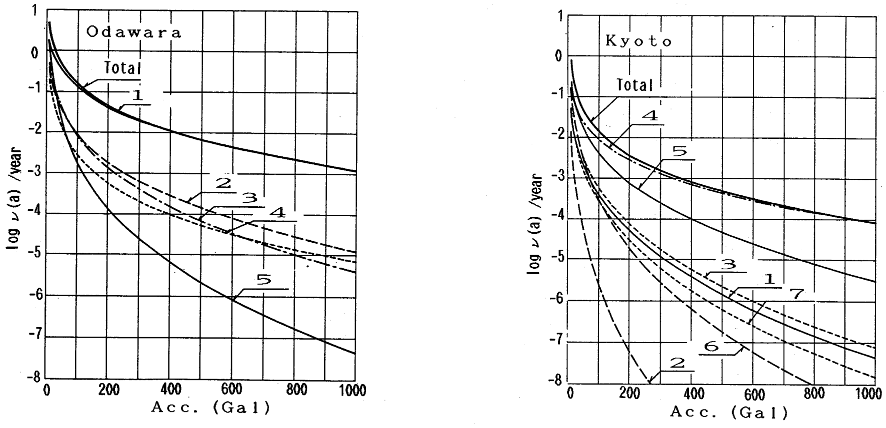

Figure 5. Annual Mean Occurrence Number of Earthquake in Each Seismotectonic Zone

Figure 5 shows the annual mean number $\nu(a)$ of events with $A_{max}>a$ for each seismotectonic zone at Odawara and Kyoto. At Odawara, $\nu(a)$ value of Zone No.1 is the largest, and Zone No.4 at Kyoto. The seismotectonic Zone No.1 corresponds to the subduction region along the Sagami Trough. The reasons of large $\nu(a)$ value of this zone are high seismic activity and short distance to Odawara. The Zone No.4 beneath Kyoto has relatively low seismic activity, while the distance to Kyoto is short. This indicates that the distance is the most important parameter to determine the seismic hazard in term of peak ground acceleration. It is because the peak ground acceleration, which is dominantly affected by short period components of seismic waves, is steeply attenuated to the distance in comparison with the peak velocity and the peak displacement.

Total sum of $\nu(a)$ of each zone is also indicated in Figure 5. The value at Odawara is larger than that at Kyoto.

On Active Fault

the active faults treated in this study are located inland. For the calculation of the peak ground acceleration, the hypocentral distance X used for the attenuation relationship is assumed as an random value uniformly distributed along the fault at the focal depth of $7.5\,km$, which is an average value for earthquakes occurring in the crust. Figure 6 shows $\nu(a)$s calculated for some of the typical active faults and total sum of $\nu(a)$s for all the detected active faults at Odawara and Kyoto. Most of the active faults shown in the figure are near to the sites and located in Zone No. 1 at Odawara and in Zone No. 4 at Kyoto of historical earthquake data case. The faults (3), (4) and (5) at Odawara, which are connected to Sagami Trough, strongly affect the total value of $\nu(a)$, while, at Kyoto, there are no clearly dominant active faults with large $\nu(a)$ and the value of each fault is rather uniform.

As for the total sum $\nu(a)$ value, it is larger at Odawara than that at Kyoto. It may be due to relatively higher activity of the faults around Odawara.

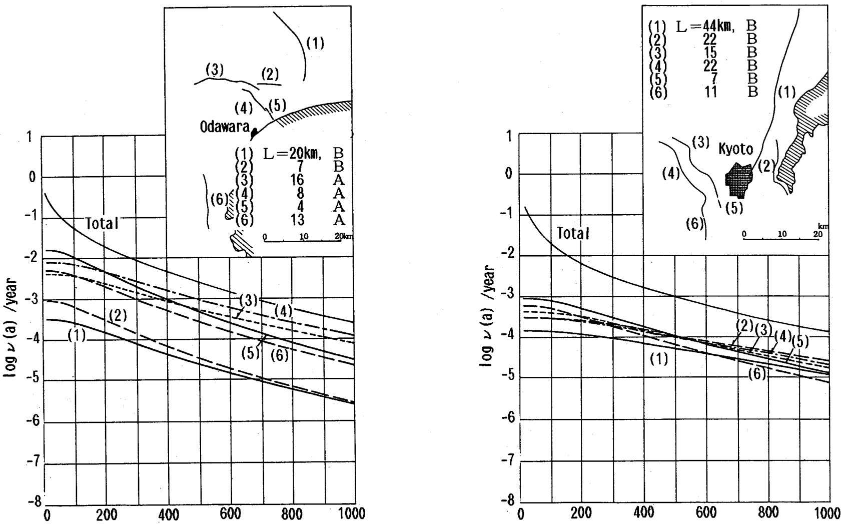

Figure 6. Annual Mean Occurrence Number of Earthquake of Each Fault

DISCUSSION AND CONCLUSIONS

Figure 7 shows the seismic hazard curves estimated by both methods at Odawara and at Kyoto. At Odawara, the hazard curve estimated based on the historical earthquake data is larger than that on the active fault data, while the difference of them is not so remarkable at Kyoto. It may be said that, at Odawara where the seismic hazard mainly depends on the active seismic region under the sea, the hazard curve would be underestimated when we use only inland active fault data. On the contrary, the method based on the active fault data is applicable at Kyoto, where the seismic hazard is strongly influenced by the inland earthquakes in the crust.

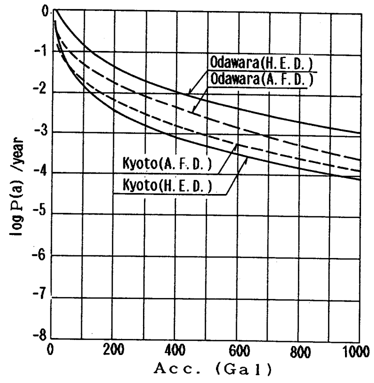

Figure 7. Comparison of Hazard Curves

Historical earthquake data are the records of the facts during rather short period. If we use only the data, the seismic hazard estimation would give the lower bound. In this study, to avoid this disadvantage, we defined M_{max} larger than the maximum magnitude in the history, considering the tectonics of each seismotectonic zone.

On the other hand, the active fault data give us an average seismic hazard over a long period. However, our understandings of active faults are still limited and the surveys are not enough. In other aspect, if the recent seismic activity around the site is apparently higher than ever, the hazard curves based on the active fault data should not be adequate.

Both data have incompleteness for precise modeling of seismic sources, but, at the same time, they are almost only data available at present.

In application of the presented two methods, although, modeling of seismic sources are completely different, the estimated hazard curves are consequent where both data are available as at Kyoto. This may be partly because we consider large variability in the attenuation relationship, however, the similarity of the results suggest us the applicability of both methods for seismic PRA.

For the estimation of seismic hazard curve at sites where active fault observation is not completed such as located near to the subduction regions under the sea with high seismic activities, the use of historical earthquake data is recommended. At sites, where both data are prepared, both approach should be taken. If the results have large difference we should find out the reasons and this step will help us to understand the seismic circumstances better.

REFERENCES

ANN/IEEE, PRA Procedures Guide, NUREG/GR-2300, 1983.

H.Ishida et al., Seismic Risk Analysis Using both Earthquake Data and Active Fault Data, Inter. Sympo. on Natural and Man-Made hazards, 1986.

H.Kameda and T. Okumura ,Seismic Hazard Estimation Based on Active Fault Data and Historical Earthquake Data, Proc. of JSCE, 326, pp. 407-415, 1985.

K.Kanai et al., Observation of Strong Earthquake Motions in Matsushiro Area Part 1, Earthq. Res. Inst., 44, pp.1269-1296, 1966.

Research Group for Active Faults of Japan, Active Faults in Japan, Univ. of Tokyo Press, 1980

H.B.Seed et al., Characteristics of Rock Motions during Earthquakes, J. of ASCE, 95, pp.1199-1218, 1969.

M.Takemura et al., A Seismic PRA Procedure in Japan and Its Application to a Building Performance Safety Estimation Part 1., The 5-th ICOSSAR, 1989.

M.Tomatsu et al., characteristics of Seismic Hazard Map Based on the Inland Active Faults, Meeting of Earthq. Eng. of JSCE, pp. 21-24, 1983.

T.Usami, Materials for Comprehensive List of Destructive Earthquakes in Japan, Univ. of Tokyo Press, 1975.

S.G. Wesnousky et al., Earthquake Frequency Distribution and the Mechanics of Faulting, J. Geophys. Res., 88, pp. 9331-9340, 1983.