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A NON-PARAMETRIC APPROACH FOR ESTIMATION OF PEAK HORIZONTAL ACCELERATION IN JAPAN

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ABSTRACT

An artificial neural network model was developed to predict peak horizontal acceleration in Japan. A complete data set with large number of records of Japanese subduction zone data was considered for the analysis. The local site condition is included into the proposed model, where two types of ground were selected during analysis. Prediction curves related to the soil and rock sites were notably resolved. For comparison some recent attenuation studies in Japan were investigated. It is found that the attenuation of peak horizontal acceleration provided by this study is compatible with other recent attenuation studies in Japan and has relatively superior performance in some instances.

INTRODUCTION

The empirical predictive relations of earthquake ground motion parameters have quite important role to the seismic hazard analysis. Such relations are generally expressed as mathematical functions relating a strong motion parameter to the parameters characterizing the earthquake source, the propagation path distance and the local site conditions.

Peak horizontal acceleration is one of the earthquake ground motion parameters that is of considerable interest to the earthquake engineer and seismologist. It is one of the major factors for earthquake resistant design in important engineering structures and huge economical and industrial facilities especially in the area located on the active seismic zone.

During the past few decades several attempts have been made to estimate the peak acceleration with various pertinent properties of the strong motion records, *e.g.* Gutenberg & Richter [1]; Housner [2]; Trifunac [3]; Joyner & Boore [4]; Campbell [5], [6]; Anderson & Yutain [7] *etc.*.

In Japan, Kanai *et al.* [8] were the first who studied acceleration attenuation relation, using data observed in the Hitachi mine and the source region of the Matsushiro earthquake swarm. Subsequent regression analyses have been conducted by many researchers as the amount of observed data has increased, such as Kawashima *et al.* [9]; Tanaka *et al.* [10]; Annaka & Nozawa [11]; Fukushima & Tanaka [12]; Iai *et al.* [13], and Molas & Yamazaki [14], [15] *etc.* on the Japanese subduction zone data during the last two decades.

Regression analysis, with various functional forms and procedures, has been widely utilized by Japanese researchers to estimate attenuation relations in Japan. In general, regression analysis is a technique for fitting curves (linear or nonlinear surfaces) to the data points. Simpson [16] points out that the nodal function used in many error correction learning algorithms of neural networks is a family of curves, and that the adjustment of the weights that minimize the overall

Table 1 Summary of recent strong motion attenuation relations in Japan (1986 - 1995)

Reference	Applicability	Parameter*	Attenuation relation	Number**
Kawashima *et al.*, 1986	r = Rock	$M = M_J$	$\log PGA_r = 987.4+0.216M-0.218\log(\Delta+30)$	$N_r = 197$
	h = Hard soil	$\Delta = R_e$	$\log PGA_h = 232.5+0.308M-1.218\log(\Delta+30)$	$N_e = 90$
	s = Soft soil		$\log PGA_s = 403.8+0.265M-1.218\log(\Delta+30)$	$N_s = 67$
Annaka and Azawa, 1988	$300 \leq V_S \leq 600$	$M = M_J$	$\log PGA = 0.627M+0.00671H-2.212\log D$	$N_r = 319$
		$H = D_f$	$+1.711+0.211P$	$N_e = 45$
		$R = R_h$	$D = R+0.35\exp(0.65M)$	
Fukushima and Tanaka, 1990	$0.1<R<300$	$M = M_S$	$\log PGA = 0.41M-\log(R+0.032\times10^{0.41M})$	$N_r = 686$
	$4.5 \leq M \leq 7.8$	$R = R_c$	$-0.0034R+1.30$	$N_e = 43$
Iai *et al.*, 1993	$10<R<1000$	$M = M_J$	$\log PGA = 0.552M-1.965\times\log(\Delta+30)+2.103$	$N_r = 726$
	$4.0<M<8.0$	$\Delta = R_e$	$\log PGA = 0.559M-2.0571\times\log X+2.187$	$N_e = 92$
		$X = R_h$	$\log PGA = 0.490M-\log X+0.634$	$N_s = 55$
Molas and Yamazaki, 1995b	$1 \leq R \leq 700$	$M = M_J$	$\log PGA = 0.184+0.482M-\log R-0.00149R$	$N_r = 2206$
	$4 \leq M \leq 7.8$	$R = R_h$	$+0.00315H+C_i+0.278P$	$N_e = 388$
		$H = D_f$	$\log PGA = 0.206+0.477M-\log(R+C(M)$	$N_s = 76+42$
		$C_i = S_c$	$-0.00144R+0.00311H+C_i+0.278P$	
			$C(M)=d_1\exp(d_2M)=0.82$	

* M_J: JMA Magnitude; R_e: Epicentral Distance; R_h: Hypocentral Distance; R_c: Closest Distance to the Fault Rapture; D_f: Focal Depth; S_c: Site Coefficient; V_S: Shear Wave Velocity

** N_r, N_e and N_s are number of records, earthquakes and stations respectively

mean-squared error is equivalent to the curve fitting.

The capability of artificial neural networks to predict ground motion parameters is proved in our previous study, (Emami et al., [17]). Here an attempt is directed towards prediction of peak horizontal acceleration in Japan on the Japanese subduction zone data.

The objective of this study is to examine various kinds of squashing functions, and network structures for estimation of peak horizontal acceleration in Japan. Then, the result of our analysis is to be compared with previous attenuation relationships in Japan. The uncertainty involved in the prediction of the peak horizontal acceleration was examined through the analysis of residuals.

In this study, the effect of ground conditions on the prediction of peak horizontal acceleration, rather than the other two main parameters (related to the size of the earthquake and the path effect) is included in the neural network model. The significance of this parameter is effectively evaluated through analysis of data from various ground conditions.

The effect of focal depth on the attenuation of ground motion, investigated by Annaka & Nozawa [11] and Molas & Yamazaki [14] will be discussed later. It is proved that the focal depth has positive influence on the attenuation of ground motion. By increasing the focal depth, the magnitude of ground motion will be increased, but the behaviour of a deep focus earthquake is not certainly known because of a high Q zone. However, since our interest is placed on the empirical prediction of ground motion acceleration from shallow to middle events, we do not attempt to use focal depth as a part of analysis. Some recent attenuation relations for peak horizontal acceleration in Japan are given in Table 1.

RECENT ATTENUATION STUDIES IN JAPAN

Herein a brief review of several recent attenuation studies in Japan will be described:

a) Kawashima *et al.* [9] studied attenuation of peak ground motion with various functional form based on multiple regression analysis. A total of 197 sets of two horizontal components of strong motion accelerations were used in their analysis. For investigation of local site effects the data was classified based on three kinds of soil conditions: rock, hard soil, and soft soil. The accuracy of attenuation relations was determined by multiple correlation coefficient, which was considered as a basic parameter to select an adequate model. A model with the highest value of the correlation coefficient, which was finally selected by them, is given in Table 1. Based on their relationship, the attenuation curves, regarding the soft ground, have lower values for magnitude:

Table 2 Comparison of recent attenuation studies in Japan

Studies	Number of records two component pair	Number of earthquake	Magnitude range	Distance range	Focal depth	Recording station	Definition of peak horizontal acceleration	Analytical method
Kawashima *et al.* 1986	197	90	$5.0 \leq M_J \leq 7.9$	$5.0 \leq Dis. \leq 500$	$h \leq 60$ km	67 free field	maximum resultant of combination of two horizontal components	single step regression (multiple linear regression)
Fukushima and Tanaka 1990	486 (Japan) 200 (USA)	28 (Japan) 15 (USA)	$4.6 \leq M_S \leq 8.2$	$0.1 \leq Dis. \leq 303$	$h \leq 30$ km (Japan) $h \leq 20$ km (USA)	not specified	mean of two horizontal components	two step stratified regression
Molas and Yamazaki 1995b	2206	388	$4.0 \leq M_J \leq 7.8$	$0.2 \leq Dis. \leq 1000$	$0 < h \leq 200$ km	76 free field + 42 Non JMA Great Hanshin Earthq.	larger of two horizontal components	two step regression (partial iterative regression)
This study	1652	313	$4.2 \leq M_J \leq 7.8$	$4.6 \leq Dis. \leq 1000$	$h \leq 65$ km	76 free field	larger of two horizontal components	artificial neural network (multilayer networks with b-p. learning)

5, 6, 7; and the rock and hard soil have unsystematic trends in accordance with magnitudes 6.0 and 7.0. It can be concluded that the effect of ground condition on the attenuation of peak ground acceleration in their model seems to be unrealistic.

b) Anaka and Nozawa [11] proposed an attenuation model for estimation of seismic hazard in the Kanto district (Japan). The data collected by TEPCO's network was used to obtain the attenuation equation of peak horizontal acceleration. They noted that the provided equation is applicable to the site where the surface Vs are between 300 and 600 m/s. The authors used records related to the 45 earthquakes with focal depths less than 100 km. The obtained attenuation relation from multiple linear regression is given in Table 1.

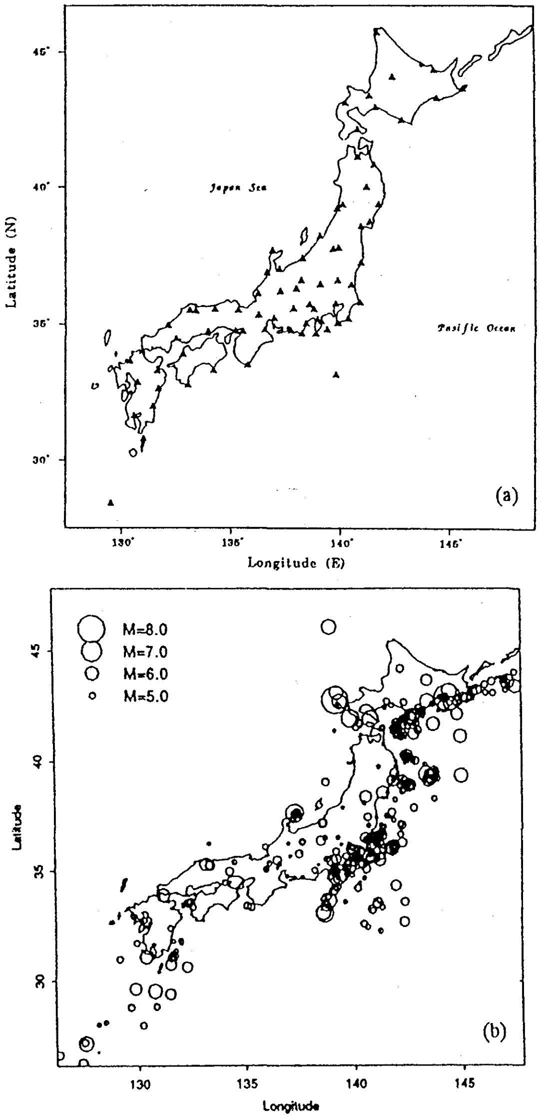
The effect of focal depth on the attenuation equation was examined by investigating two major and disastrous earthquakes of: 1885 Ansei-Edo earthquake (M_J=6.9) and 1894 Tokyo earthquake (M_J=7.0), as is noted in their paper. This effect is introduced into the attenuation relation by considering a parameter related to the focal depth. The focal depth has a significant positive influence on the prediction of peak horizontal acceleration.

c) An attenuation relation of peak horizontal acceleration applicable to the near source in Japan is developed by Fukushima & Tanaka [12]. The 1,372 horizontal components of peak ground acceleration from 28 earthquakes in Japan and 15 earthquakes in the United States and other countries were used in their analysis.

The two step stratified regression procedure was used for analysis of data. Their model accounts for geometrical spreading and anelastic attenuation, but has magnitude-independent shape at very short distances. Their attenuation model is also presented in Table 1.

d) An attenuation study of earthquake ground motion in Japan, including deep focus events, was conducted by Molas and Yamazaki [14]. Several recent large earthquakes are included in their data set. The data set consists of 2,166 horizontal components from 387 earthquake events. This data set is significantly unique in Japan for analysing the attenuation of ground motion so far. The effect of focal depth on the attenuation of ground motion has been investigated while examining two recent major earthquakes: 15 January 1993, Kushiro-Oki earthquake (M_J=7.8, Focal depth=103.2 km) and 12 July 1993, Hokkaido Nansei-Oki earthquake (M_J=7.8, Focal depth=34 km). The significant positive effect of focal depth on the attenuation of ground motion was investigated. By considering this fact, a parameter relating to focal depth was introduced to the attenuation relation. The authors reconsidered their study with regard to the data from the most recent and largest earthquake of 17 January 1995, the Great Hanshin earthquake. The final attenuation relation for peak horizontal acceleration was formulated into two forms, as presented in Table 1.

For analysis of acceleration data, the iterative partial regression method was used based on the two step regression procedure in their study. The local ground condition was considered by examining the station effect instead of the soil type classification. A coefficient regarding the station effect was included in the analytical model. The site coefficient is related to the site condition, including geology, topography and other possible affective factors. The authors noted that if the proper site coefficient is obtained, then the determination of the seismic hazard will be more accurate. However, determining the adjusted site coefficient for specific site under



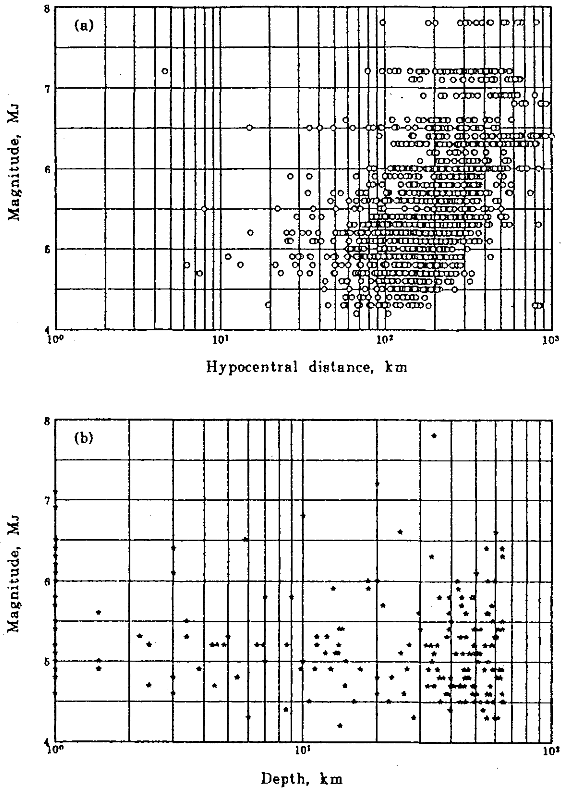


Fig. 2 Distribution of observed data with respect to magnitude - distance (a), and - depth (b)

Left Figures:
Fig. 1 Location of JMA recording stations (a) and epicenters of earthquakes (b) used in this study (after Molas and Yamazaki, 1995b)

consideration is difficult. The various characteristics of the previous studies in Japan were compared with our study in Table 2.

THE ACCELERATION DATA

The data was recorded by the Japan Meteorological Agency (JMA) recording networks around the Japanese territory. In the past, the recording instrument was SMAC-B2 accelerometers, which had sensitivity limitations at high frequencies. Since 1987, the Japan Meteorological Agency (JMA) has started to install the new JMA-87-type accelerometers in the recording stations throughout Japan. The advantage of the data supplied by the new accelerometers is that it does not need correction, and the errors involved in the correction procedure can be avoided. The records can be considered as free field because of small foundations in the base of accelerometers and their detachment from the structure that houses the accelerometers (Molas & Yamazaki, [14]). Since the geological conditions of the recording station were investigated, it is possible to study the effects of local site on the attenuation of earthquake ground motion.

The data from the period of 1 August 1988 to 31 December 1993, which is recorded at 76 JMA station, was considered for the analysis. Recent damaging earthquakes, such as 7 February 1993 Noto Pensinsula-Oki earthquake (M_J=6.6, Focal depth=24.8 km) and the 12 July 1993 Hokkaido Nasi-Oki earthquake (M_J=7.8, Focal depth=34 km), are included in the data set.

The location of JMA stations (triangles) and the epicenters of earthquakes (circles) used in this study are shown in Figure 1.

The data set consists of 1,652 recordings of peak accelerations from 313 earthquake events, including data from the most recent earthquake, the Great Hanshin Earthquake, 17 January 1995 (M_J=7.2, focal depth=20km). Since there are so few near field strong motion records available in Japan, the near field data provided by the Great Hanshin Earthquake has made an opportunity to study attenuation characteristics at the near distance in Japan. However, because of the lack of information regarding the soil conditions at the Non-JMA recording stations, this data could not be included in the data set. Fukushima & Tanaka [12], used the near field data from the USA to complete their data base in the investigation of attenuation in the near field in Japan.

Earthquakes with focal depths greater than 65 km were not included in the data set to avoid the effect of the high-Q zone (Fukushima & Tanaka, [12]). The distribution of observed data, with respect to the magnitude, distance, and depth, are illustrated in Figure 2.

The analysis was performed on the peak horizontal acceleration. The peak horizontal acceleration is defined as the largest value of two horizontal components of a given record. Kawashima *et al.* [9] calculated the maximum ground motion on the horizontal plane while the mean value of two horizontal components was utilized by Fukushima & Tanaka [12].

The distance in which the data is obtained ranges from less than 4 km to 1000 km. Various definitions of distance were used by researchers in the study of attenuation relations, such as epicentral distance, hypocentral distance, closest distance to the fault rapture, and so forth. For the near field data the reliable distance definition becomes more important, especially for earthquakes with a large fault extent. The nearest distance to the earthquake source (hypocentral distance) was considered in our analysis, except for the Great Hanshin Earthquake, in which the shortest distance to the fault rapture was used.

ANALYTICAL PROCEDURE

In Japan, typically, one and two step procedures of regression analysis have been used for prediction of ground motion parameters so far. As mentioned in the previous section, Kawashima *et al.* [9], examined various functional forms, based on the multiple regression analysis, to predict ground motion parameters. A two step stratified regression analysis was considered by Fukushima & Tanaka [12], to predict peak ground acceleration. The authors point out that the distance coefficient depends on the value of the magnitude coefficient, if the event's magnitude and measurement distance are simultaneously used in the regression analysis. They proved this fact through a numerical experiment, as well as through their actual data. To avoid this interaction between the coefficients of magnitude and distance, the two step stratified regression method, using a dummy variable, has originally been found to be very effective by Joyner & Boore [4]. Recently, a work was done by Molas & Yamazaki [14], on the prediction of ground motion in Japan. A predictive model based on the two step procedure was introduced for prediction by the iterative partial regression method. Their emphasis was on the focal depth and its effect on the attenuation relations. For a detailed explanation of the one and two step regression analysis, see Joyner and Boore [18].

The capability of artificial neural networks to predict ground motion parameters was first proven by Emami *et al.* [19]. This method provides an analytical procedure in which neither functional form nor independence of inside variables is needed. That means the dependence between two measured predictive parameters, magnitude and distance, has no negative effect on the accuracy of prediction. An artificial neural network model based on multilayer networks was considered for the analysis of acceleration data in Japan. The designed networks have a hidden layer consisting of 45 units. The output layer of the considered networks is constructed using a sigmoidal or linear unit, while the hidden layer is constructed using only sigmoidal units. Through analysis of acceleration data it has shown that the sigmoidal unit in the output layer produce more accurate estimation than linear. To train this feed-forward network, the classic back-propagation learning algorithm was used. The back-propagation learning algorithm is well known for its ability to generalize well on a wide variety of problems. That is why it is used for the vast majority of neural network applications. It is a very efficient algorithm, that is generally used in the multilayer artificial neural networks. The back-propagation algorithm trained the networks model within several hundred iterations, depending on the number of hidden units installed. The multilayer artificial neural networks and back-propagation algorithm are discussed in detail in Zeidenberg [20].

As mentioned, our network model consists of three layers, with 45 sigmoidal nodes in the hidden layer and a sigmoid output unit. Inputs to the network are the earthquake magnitude, distance and local ground condition as described earlier. Peak horizontal acceleration is expressed as the logarithm of acceleration (cm/s^2), which was normalised and considered as a target. The input data to the network was also normalised based on maximum values of each input parameter, in order to homogenise the weight values. The network has been examined through many training procedures in order to find out the suitable structure and to finally get a better adjustment for the root-mean-square error cost function. The our designed network model is presented in Figure 3.

Simpson [16], noted that creating the best possible set of features and properly representing those features is the first step toward success in any neural network application. In this regard, the input parameters to the network model were reconsidered from our prevision studies. The ground conditions are also successfully included as predictive parameters. Ground condition is considered as the dummy variable. This variable is introduced into the network as the third and fourth input parameters. Various types of ground conditions were examined during the analysing of peak horizontal acceleration. In the end, two ground types were selected, namely, the rock and soil types. Soft soil could not be properly included into the analytical model, due to the lack of enough available records. Only 83 records from four recording stations are available; that is about 5 per cent of the complete data set.

RESULTS & DISCUSSION

Local Ground Conditions

As mentioned earlier in the recent study of attenuation relations in Japan conducted by Kawashima *et al.* [9] and Molas & Yamazaki [14] the effect of local ground condition were examined. The final attenuation model introduced by Kawashima *et al.* [9], the effect of ground condition, is not correctly defined by their predictive curves related to the M_J=5, 6 and 7, as it can be seen from Figure 4. In all cases soft soil has a lower value of acceleration than rocky ground. Molas and Yamazaki [14], introduced a term into their predictive model, based on the local site effect for each recording station. This effect was also verified by examining the residuals, with respect to the recording station. Although other effective factors of site, rather than soil type were included in this term, but from the practical point of view, the determination of the term for a specified site under consideration is not easy based on their model.

The ground condition is considered as an effective factor in the prediction of peak horizontal acceleration in our analysis. The acceleration data was recorded by several stations located on the various ground conditions. The ground conditions of the recording stations were investigated by the Japan Meteorological Agency based on their classification system. In this system four types of ground were introduced: rock; hard soil, medium soil, and soft soil. In the predictive model of neural networks, the effect of ground conditions on the prediction of peak horizontal acceleration was examined by introducing a dummy variable into the model as the third and

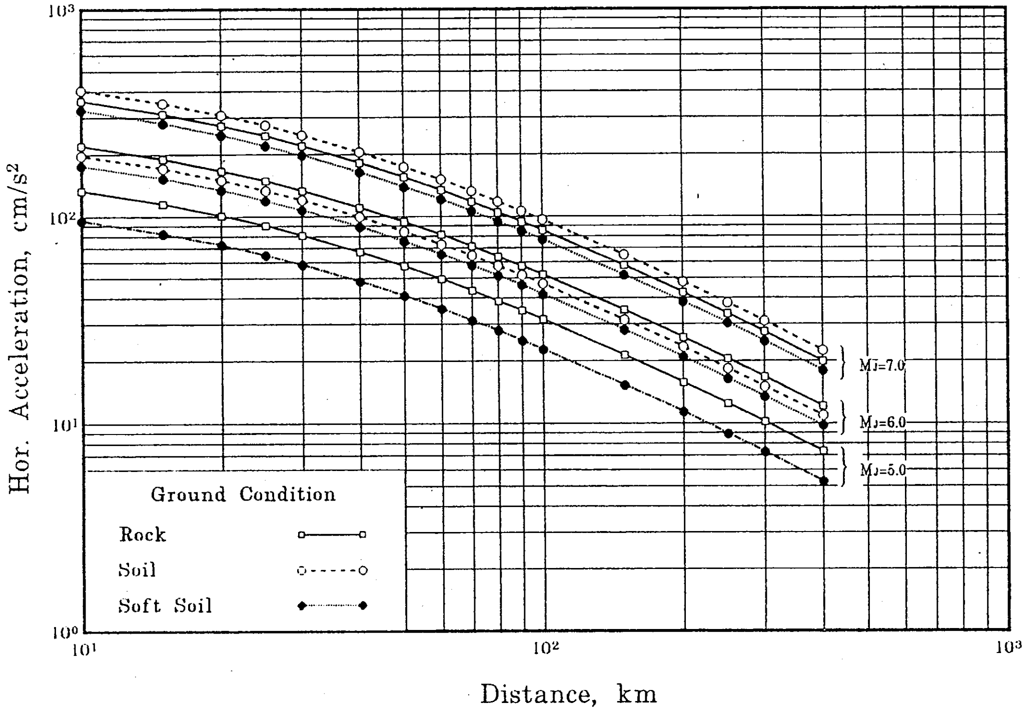


Fig. 4 Attenuation curves of peak horizontal acceleration, proposed by Kawashima *et al.* (1986)

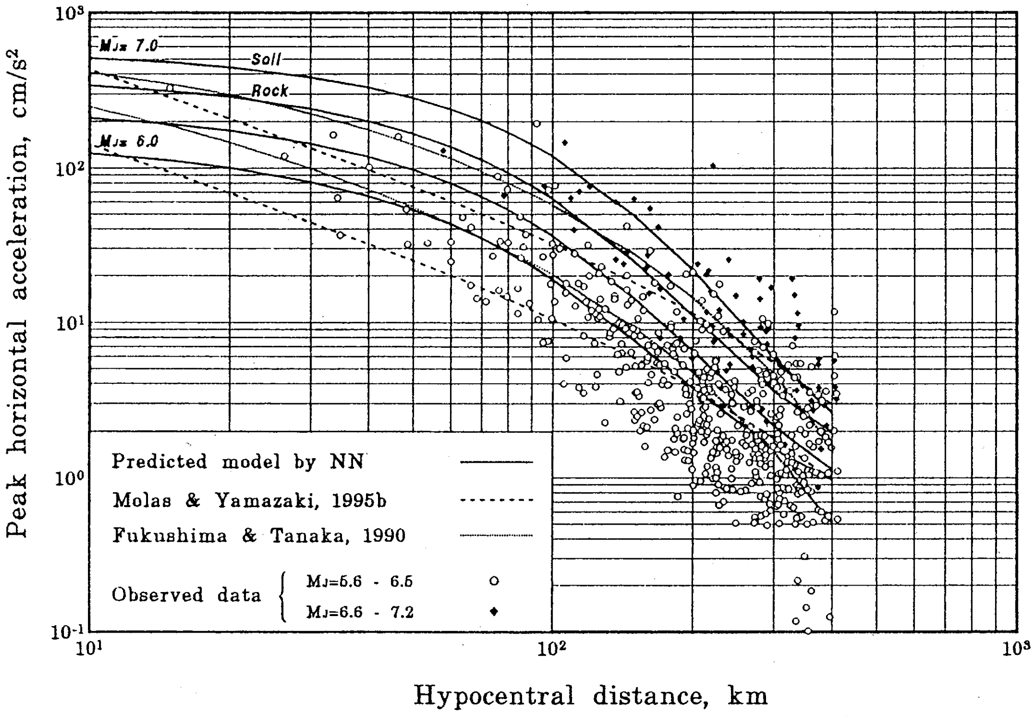


Fig. 5 Observed peak horizontal acceleration and model - based predictions for magnitude 6 and 7 compared with attenuation curves of Fukushima & Tanaka (1990) and Molas & Yamazaki (1995b)

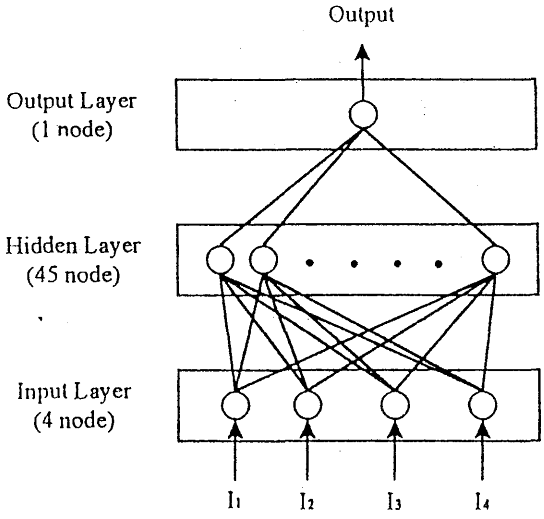


Fig. 3 The structure of applied neural network model with back-propagation error correction

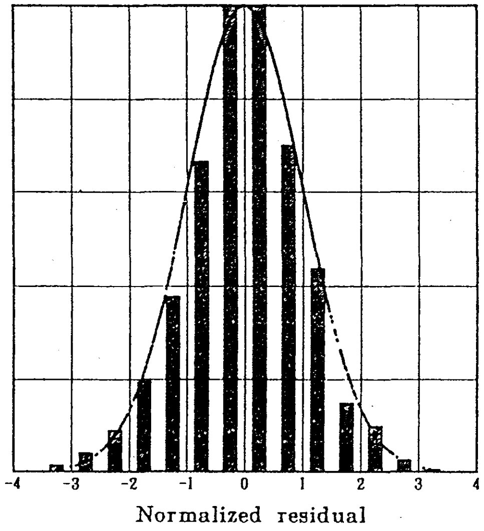


Fig. 7 A normal probability plot of normalized residuals

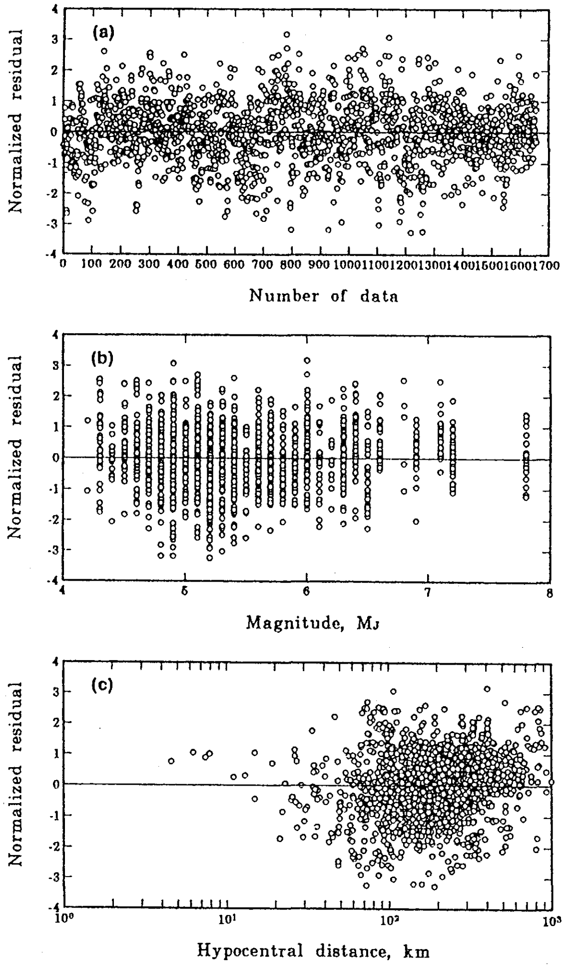


Fig. 6 Plots of residuals with respect to time (a), magnitude (b), and distance (c), according to our model

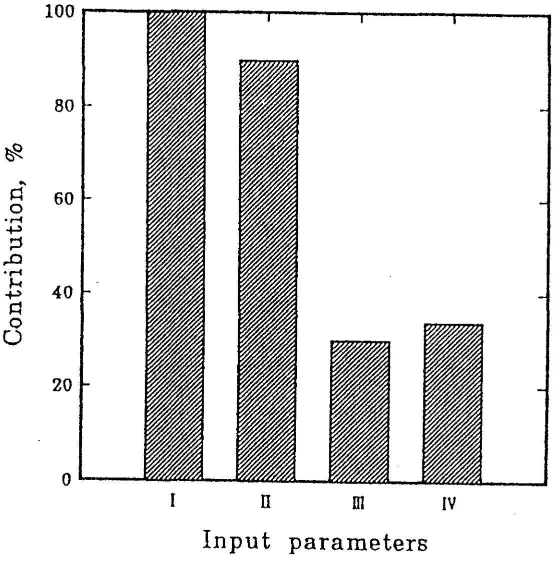


Fig. 8 The contribution of input parameters to the prediction of peak horizontal acceleration

fourth input parameters. This technique is commonly used by several investigators to verify the performance of the ground condition on the ground motion parameters at the specific site. (McGiure, [21]; Kawashima *et al.*, [9]; Joyner & Boore, [22]). The technique is based on a soil-type classification by using a dummy variable for each ground type. Due to the lack of enough recording data of soft soil, the two major types of ground, rock and soil are effectively investigated by this analysis. The attenuation curves belonging to the soil and rock types of ground for magnitudes 6.0 and 7.0 are illustrated in Figure 5. The soil type has values of acceleration about 50 per cent higher than those of the rock type.

Analysis of Residuals

The overall adequacy of the model is best assessed from an analysis of residuals (Draper and Smith, [23]). A residual is simply defined as a difference between the observed and predicted values of acceleration, on the basis of a logarithmic scale.

The residuals were normalized to have mean and a standard deviation of unity. Analysis of residuals is done to test the potential biases in the prediction. In the first step in order to define biases in the prediction, plots regarding the residuals with respect to the data number, magnitude, and distance are made. The plots are carefully inspected to define any systematic trends in the data. If the systematic trends are not accounted for by statistical analysis, it should be evident from these plots. The mentioned plots presented in Figure 6. No significant trend in the residuals appears in these plots. A correlation analysis is performed for residuals and all parameters considered in the model. This is done to test the statistical significance of the probable trends in the residuals, with respect to the parameters. This analysis confirmed that the residuals were uncorrected with respect to these variables.

The adequate model required a normal distribution of residuals. The residuals were normalized to have mean zero and a standard deviation of unity. The normalized residuals resulting from the analysis is perfectly, normally distributed, as can be seen in Figure 7. The normal distribution of residuals is emphasised by Campbell [5], [24], as a fundamental requirement of model adequacy. A qualitative assessment of normality may be obtained by inspecting a histogram of residuals. Campbell [24] noted that it should resemble the standard bell shape of the normal distribution.

An investigation is performed to evaluate the contribution of input parameters to the model under prediction. In this respect, the values of weights in the Input-Hidden connection link were considered. The result of the contributed study is presented in Figure 8. As it can be seen from this Figure, earthquake magnitude has the highest contribution and the local ground condition has the lowest contribution to the prediction of peak ground acceleration. Shortest distance has about 90 per cent of the contribution compared to the magnitude.

The designed network model could effectively provide an accurate estimation of peak horizontal acceleration. Prediction curves of the neural network model for magnitudes 6.0 and 7.0 are compared with attenuation relations of Fukushima & Tanaka [12] and Molas & Yamazaki [15] in Figure 5. The prediction of this study is relatively high compared to the other study. It may be due to the provided data of the Great Hanshin Earthquake, 1995. The forms of both attenuation curves of this study and the ones belonging to the study of Fukushima & Tanaka [12], are nearly similar.

Figures 9(a & b) are constructed in accordance with our proposed neural networks, and might be used to estimate the peak horizontal acceleration in Japan for practical usage. Due to the very small number of data in the near field (only four records for distance less than10 km), the prediction is valid for distance ranges from 10 to 400 km. With regard to the magnitude range of the data, the analysis is limited on the magnitude in the range of 4.5 to 7.5 in JMA scale.

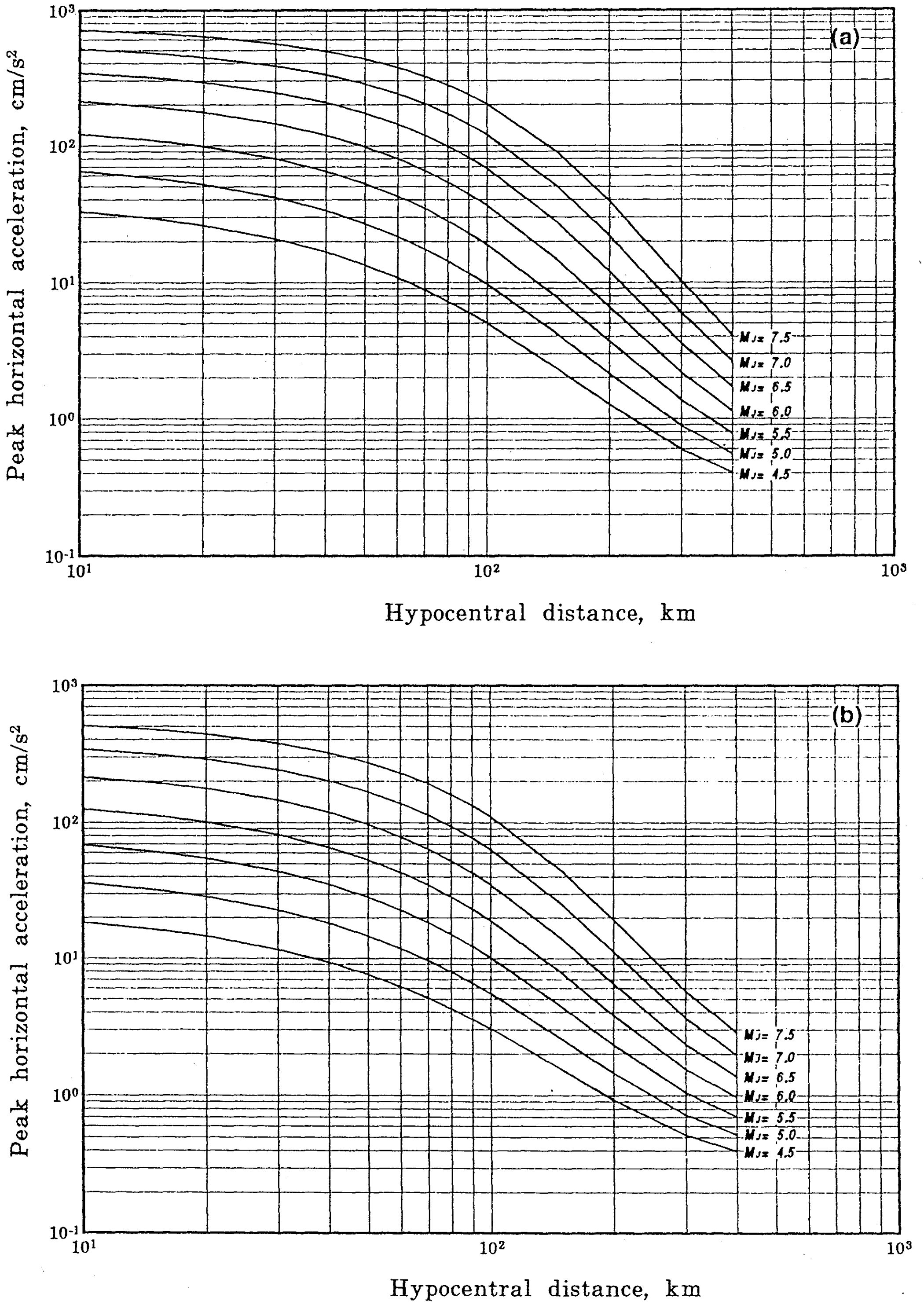


Fig. 9 Predicted values of peak horizontal acceleration as a function of distance and magnitude, using our neural network model for soil (a) and rock (b) sites which can be used in the practical fields

CONCLUDING REMARKS

A large and completed data set, well distributed over the distance and magnitude range, was available for analysis. The near source data provided by the very recent earthquake in Japan, the Great Hanshin Earthquake (15 January 1995) is included in the data set.

Japanese subduction zone data were analysed by the artificial neural network model. The results show the attenuation of peak horizontal acceleration provided by this study is compatible with other recent attenuation studies in Japan and has relatively superior performance in some instances. The result is suitable for use in Japanese territories or other regions with similar tectonic environments. It is recommended that the obtained results should be used in distance ranges between 10 - 400 km and magnitude ranges between 4.5 - 7.5 in the practical field. The residuals analysis confirm that the developed predictive model is adequate to be considered in the estimation of peak horizontal ground acceleration in Japan.

It can be concluded that the obtained attenuation of peak horizontal acceleration is in agreement with that of Fukushima & Tanaka (1990), from the attenuation characteristics point of view. Effectively, site condition is included in the prediction of peak horizontal acceleration by the artificial neural network model. Prediction curves related to the soil and rock sites were notably resolved. This result is one of the few successful studies of the effect of ground conditions on the prediction of peak horizontal acceleration in Japan.

REFERENCES

1. Gutenberg, B. and Richter, C.F. "Earthquake magnitude, intensity, energy and acceleration". *BSSA*, Vol. 46, pp. 105-195 (1956).
2. Housner, G.W. "Engineering estimates of ground shaking and maximum earthquake magnitude". *Proc. 4th World Conf. Earthq. Eng., Santiago*, pp. 1-13 (1969).
3. Trifunac, M.D. "Preliminary analysis of the peaks of strong earthquake ground motion - dependence of peaks, on earthquake magnitude, epicentral distance, and recording site condition". *BSSA*, Vol. 66, pp. 189-219 (1976).
4. Joyner, W.B. and Boore D.M. "Peak horizontal acceleration and velocity from strong motion records including records from the 1979 Imperial Valley, California Earthquake". *BSSA*, Vol. 71, pp. 2011-2038 (1981).
5. Campbell, K.W. "Near source attenuation of peak horizontal acceleration". *BSSA*, Vol. 71, pp. 2039-2070 (1981).
6. Campbell, K.W. "The dependence of peak horizontal acceleration on magnitude earthquake in California and Eastern North America". *BSSA*, Vol. 79, pp.1311-1346 (1989).
7. Anderson, J.G. and Yutian L. "Nonparametric description of peak acceleration as a function of magnitude, distance and site in Guerrero, Mexico". *BSSA*, Vol. 84, No. 4, pp. 1003-1017 (1994).
8. Kanai, K., Hirano K., Yoshizawa S. and Asada T. "Observation of strong earthquake motion in Matsushiro area" (in Japanese). *Part 1, Bull. Earthq. Res. Inst., Un. of Tokyo*, Vol. 44, pp. 1269-1296 (1966).
9. Kawashima, K., Aizawa, K. and Takahashi K. "Attenuation of peak ground acceleration, velocity and displacement based on multiple regression analysis of Japanese strong motion records", *Earthq. Eng. Struct. Dyn.*, Vol. 14, pp. 199-215 (1986).
10. Tanaka, T., Fukushima Y., Sakaue M., and Yoshizawa S. "Statistical investigation on peak acceleration data of the strong motion accelerograph records" (in Japanese). *Proc. 7th Japan Earthq. Eng. Symp.*, pp. 439-444 (1986).
11. Annaka, T. and Nozawa Y. "A probabilistic model for seismic hazard estimation in the Kanto district". *Proc. 9th World Conf. on Earthq. Eng., Tokyo, Japan*, Vol. 2, pp. 107-112 (1988).
12. Fukushima, Y. and Tanaka T. "A new attenuation relation for peak horizontal acceleration of strong earthquake ground motion in Japan". *BSSA*, Vol. 80, pp. 757-783 (1990).
13. Iai, S., Matsunga Y., Morita T., Sakurata H., and Mukai K. "Attenuation of peak ground acceleration in Japan". *Proc. of Int. Workshop on Strong Motion Data, California, USA*, Vol. 1, pp. 67-69 (1993).

14. Molas, G.L. and Yamazaki F. "Attenuation of earthquake ground motion in Japan including deep focus events". *BSSA*, Vol. 85, No. 5, pp. 1343-1358 (1995a).
15. Molas, G.L. and Yamazaki F. "Attenuation of ground motion during the 1995 Great Hanshin Earthquake". *Bull. ERS*, Vol. 28, pp. 25-41 (1995b).
16. Simpson, P.K. "Foundations of Neural Networks". ***Artificial neural networks*** *, E. Sanchez-Sinenco and C. Lau (ed.), IEEE Press, New York*, pp. 3-24 (1992).
17. Emami, S.M.R., Iwao Y. and Harada T. "A method for prediction of peak horizontal acceleration by artificial neural networks". *Proc. 11th World Conf. Earthquake Eng., Acopalco, Mexico*, Paper No. 1238 (1996).
18. Joyner, W.B. and Boore D.M. "Methods for regression analysis of strong motion data" *BSSA*, Vol. 83, No. 2, pp. 469-487 (1993).
19. Emami, S.M.R., Harada T. and Iwao Y. "Prediction of peak horizontal acceleration using an artificial neural network model, *J. of Struc. Mechanics and Earthq. Eng., JSCE*, No. 549/I-37, pp. 19-26 and *J. Struc. Eng./Earthq. Eng., JSCE*, Vol. 13, No. 2, pp. 93s-104s (1996).
20. Zeidenberg, M. ***Neural network models in artificial intelligence***, Ellis Horwood Ltd. (1990).
21. McGuire, R.K. "Seismic ground motion parameter relations". *J. Geotech. Eng. Div., ASCE*, Vol. 104, pp. 481-490 (1978b).
22. Boore, D.M. and Joyner W.B. "Prediction of ground motion in North America". *Proc. of Semi. on New Development in Earthq. Ground Motion Estimation and Implication for Eng. Design Practice, ATC 35-1, Applied Technology Council, USA* (1994).
23. Draper, N. and Smith H. ***Applied regression analysis***, Second Ed., Wiley, New York (1981).
24. Campbell, K.W. "An empirical assessment of near source strong motion for a 6.6 m_b (7.5 M_S) earthquake in the eastern United States". *U.S. Nuclear Regulatory Commission Rept. NUREC/CR-3839* (1984a).