Attenuation Relation of JMA Seismic Intensity Based on JMA-87-Type Accelerometer Records

by

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ABSTRACT

Recently the new JMA intensity scale was revised and a large number of seismometers measuring the intensity were deployed throughout Japan. In this study, the new JMA intensity scales were calculated for the strong ground motion data set with 3,990 three-component records obtained by the JMA-87-type accelerometers in the period of 1988 to 1996. Then an attenuation relationship for the JMA intensity was developed and examples were presented.

INTRODUCTION

After the 1995 Hyogoken-Nanbu Earthquake, the earthquake information and early damage assessment systems become quite popular in Japan (Yamazaki, 1996). Since 1987, the JMA has been deploying the JMA-87-type accelerometers throughout Japan. The network started with 76 stations. In 1993 and 1994, several damaging earthquakes occurred in northern Japan. Hence, mainly for early tsunami warning, the number of accelerometer stations was increased to 268. After the Hyogoken-Nanbu Earthquake, the number of JMA's stations was further increased to 574. Once an earthquake occurs, intensities calculated automatically on site at 574 stations are collected immediately through the JMA's telecommunication system. Recently the Fire Defense Agency (FDA) also ventured upon a project to deploy one seismometer measuring JMA intensity in each municipality (3,255 in total). When this network is completed, the distribution of intensity due to an earthquake can be estimated even in case of a very localized event. Disaster management agencies will use these information for identifying affected areas and preparing for crisis management.

Since intensity data are most promptly obtained and largest in number, the JMA intensity will be used more frequently in early damage assessments. Considering these situations, an attenuation relationship is developed in this study using the data recorded by JMA-87-type accelerometers compiled by Molas and Yamazaki (1995) from August 1, 1988 to December 31, 1993, and Annaka et al. (1997) from January 1, 1994 to March 31, 1996.

EARTHQUAKE DATA

The acceleration records used in this study consist of 3,990 three-component sets from 1,020 events (Table 1). These data were recorded by the JMA-87-type accelerometers at 77 free field sites from August 1, 1988 to March 31, 1996. The data set includes records for some major events, such as the 1993 Kushiro-Oki (M=7.8 in JMA scale), the 1993 Hokkaido-Nansei-Oki (M=7.8), the 1994 Hokkaido-Toho-Oki (M=8.1), the 1994 Sanriku-Haruka-Oki (M=7.5), and the 1995 Hyogoken-Nanbu (M=7.2) Earthquakes. Figure 1 shows the locations of the JMA stations and the epicenters of earthquakes used in this study.

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Table 1 Summary of JMA data used in this study

No. of events	1,020
No. of records	3,990
No. of recording stations	77
Date recorded	August 1, 1988 to March 31, 1996
Instrument	JMA-87-type accelerometers
Recording Institution	Japan Meteorological Agency (JMA)
Magnitude range	4.0 to 8.1 (JMA scale)
Depth range	0.1 to 200 km

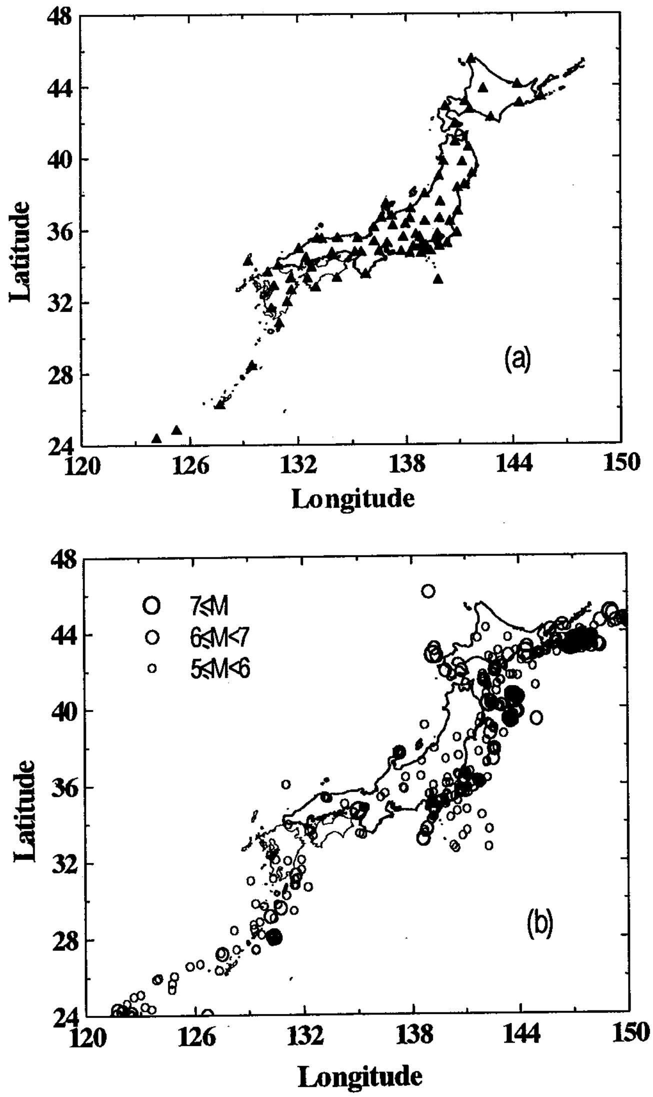


Fig. 1 Location of (a) JMA recording stations (triangles) and (b) epicenters of earthquakes (circles)

Records with peak ground acceleration (PGA) less than 1.0 cm/s^2 in one horizontal component were omitted. Events whose focal depths were zero or greater than 200 km were also excluded from the analysis. The records which are used in Molas and Yamazaki (1995) study on attenuation of PGA and PGV using the JMA data set were mostly far-field ones (1995), but in this study near-field records such as those from the 1995 Hyogoken-Nanbu Earthquake are included. Figure 2 plots the distribution of data on the shortest (slant) distance and magnitude and the depth and magnitude and also it shows the histogram of the number of records per each station. Although the new data set includes the near source data such as from the Hyogoken-Nanbu Earthquake, the lack of near-source earthquake is still seen in Figure 2.

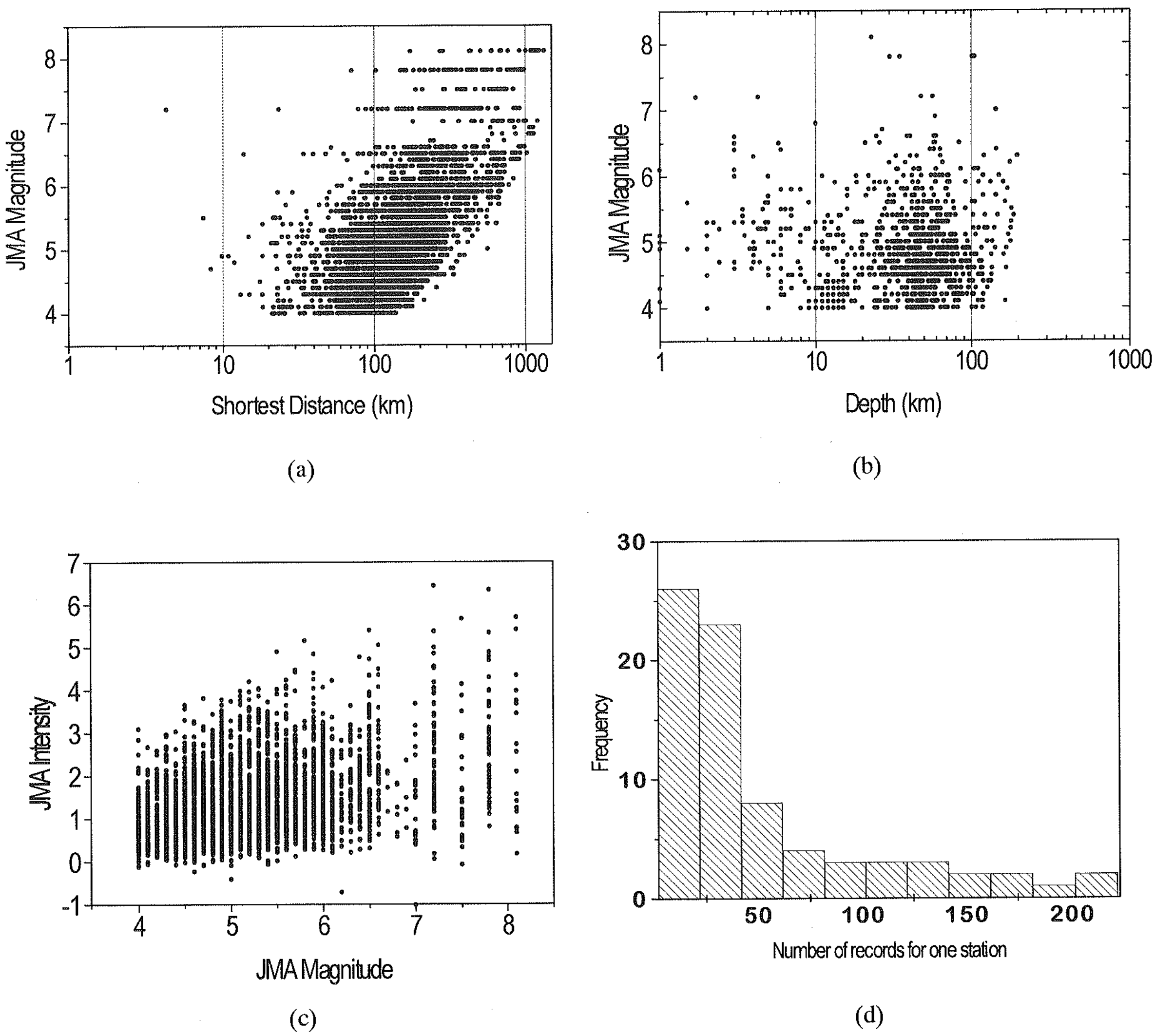


Fig. 2 Distribution of the JMA magnitude with (a) distance, (b) depth, and JMA intensity with (c) JMA magnitude for the current data set and (d) the histogram of the number of records per station

JMA SEISMIC INTENSITY

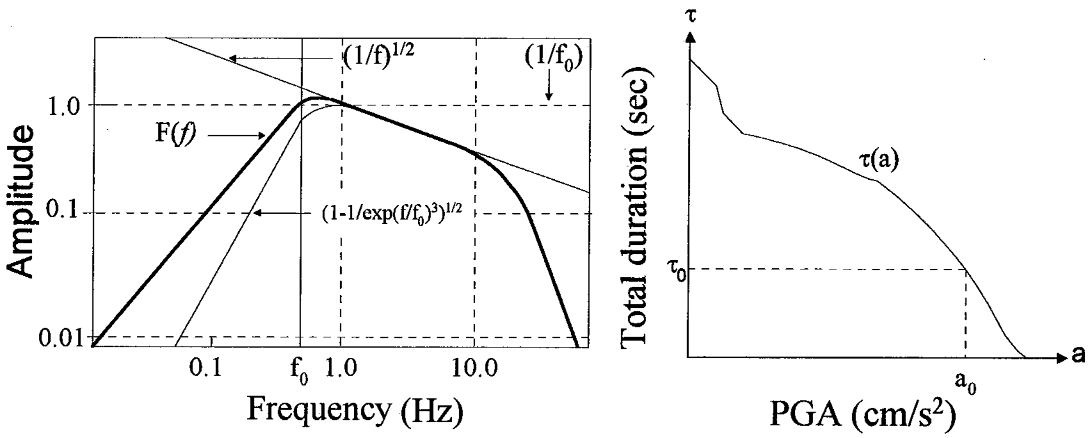
The JMA seismic intensity scale was revised recently (JMA, 1996). First, the Fourier transform is applied for the selected time window for three-component acceleration time histories. Then a band-pass filter Eq. (1) is applied in the frequency domain as shown in Fig. 3a.

$$F(f)=F_1(f)\,F_2(f)\,F_3(f) \tag{1}$$

$F_1(f)=(1/f)^{1/2}$	
$F_2(f)=U(x)$	High-cut Filter
$x=f/f_c$	$f_c=10_{Hz}$
$U(x)=(1+0.694x^2+0.241x^4+0.0557x^6+0.009664x^8+0.00134x^{10}+0.000155x^{12})^{-1/2}$	
$F_3(f)=1-\exp((-f/f_0)^3)^{1/2}$	Low-cut Filter
	$f_0=0.5_{Hz}$

Where f_c and f_0 are the high and low cutoff frequencies. After taking the inverse Fourier transform, a vectorial composition of the three-components is made in the time domain. Considering an acceleration value a_0 having total duration τ satisfying $\tau(a_0)\geq 0.3$ sec (Figure 3b), the new JMA seismic intensity I is obtained by

$$I = 2.0 \log a_0 + 0.94 \tag{2}$$



(a) (b)

Fig. 3 (a) A band pass filter in the frequency domain, (b) The total time duration of the PGA which are obtained by vectorial composition of the three components

Figure 4 shows the relation between the JMA magnitude and the calculated intensity for the current data set. The largest intensity in the data set is 6.4, which is recorded at the Kobe station during the Hyogoken-Nanbu Earthquake. The second largest intensity is 6.3, which is obtained at Kushiro station in the Kushiro-Oki event. The other intensity data are smaller than 5.5. Note that some intensity values are less than 0 because of the logarithmic function represented by Eq. (2). Applying a linear regression to the JMA intensity and PGA data sets, a new linear relation is derived for the current data set as shown in Fig. 4a with plus and minus one standard deviation levels and written by the following equation

$$I = 1.86 \log \text{PGA} + 0.23 \qquad \sigma = 0.319 \tag{3}$$

where PGA is the larger of the two horizontal components. In Fig. 4b, three others equations between PGA and intensity are plotted. By using the Molas and Yamazaki's data set, the relation can be written by Eq. (4).

$$I = 1.84 \log \text{PGA} + 0.26 \qquad \sigma = 0.291 \tag{4}$$

Although the new data are added, the standard deviation level of Eq. (3) is more than that of Eq. (4). But the relations are quit similar to each other (Fig. 4b). This can be explained due to the large number of small PGA values in the data set. Tong and Yamazaki (1996) derived the following relationship based on 205 three-component records from the 1995 Hyogoken-Nanbu (76 records), the 1994 Northridge (27), the 1993 Kushiro-Oki, the 1993 Hokkaido-Nansei-Oki, the 1994 Hokkaido-Toho-Oki, the 1994 Sanriku-Haruka-Oki Earthquakes, etc.

$$I = 1.89 \log \text{PGA} + 0.59 \qquad \sigma = 0.281 \tag{5}$$

The difference between both Eq. (3) and Eq. (5) comes from the difference of the data sets: the data of this study have mostly small intensity values while Tong and Yamazaki's data set is well distributed including data from non-JMA stations in Japan and from the United States. In Fig. 4b, the following empirical relation by Kawasumi (1943) is also plotted.

$$I_k = 2.0 \log \text{PGA} + 0.7 \tag{6}$$

Considering the improved sensitivity of recent accelerometers in the high frequency range, it may be reasonable that the recent PGA corresponds to smaller intensity as shown in Fig. 4b.

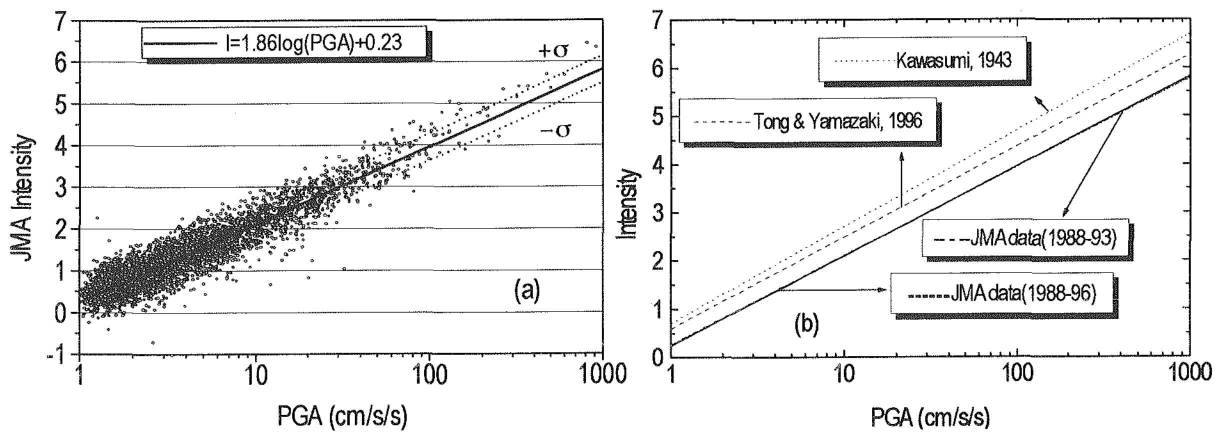


Fig. 4 Relationship between the JMA intensity and PGA, (a): JMA all data set (1988-1996) with one standard deviation and (b): comparison with previously relationships

ATTENUATION MODEL

The attenuation model for the JMA intensity in this study is given by

$$I = b_0 + b_1 M + b_2 r + b_3 \log_{10} r + b_4 h + c_i \tag{7}$$

where I is the JMA intensity, M is the JMA magnitude, r is the closest distance to the fault rupture, h is the depth, c_i are the coefficients representing local site effect of the i-th station. Note that the mean value of all the station coefficients is zero. bi's are the coefficients to be determined. The term b_2r represents anelastic attenuation and the term $b_3\log r$ represents geometric spreading. Equation (7) is basically same as those for PGA and PGV (Molas and Yamazaki, 1995) except the fact that the log scale is used for those indices. Considering the definition of the intensity (Eq. 2), the geometric spreading constant b_3 is unconstrained, or if constrained, it is set to be -2, corresponding to a spherical spreading from a point source. In this study b_3 is constrained as -1.89 following the Tong and Yamazaki relation, because their relation seems to be most reliable among other candidates. The three-stages iterative partial regression method (Molas and Yamazaki, 1995) is used to obtain the coefficients in Eq. (7). The first step determines the coefficients by one-stage linear regression. These coefficients are used as initial estimates. The second and third steps are similar to the two-stage regression procedure of Joyner and Boore (1981).

RESULTS AND DISCUSSIONS

The result of regression analysis are shown in Table 2 for the data set A (1988-1996) (Annaka et al., 1997) and data set B (1988-1993) (Molas and Yamazaki, 1995). The standard deviations for record-to-record (σ_r) and earthquake-to-earthquake (σ_e) components, and total σ ($\sigma^2=\sigma^2_r+\sigma^2_e$) do not change significantly due to increasing the number of data. Note that the predicted JMA intensity increases as the depth increases because of the positive sign for b_4. Figure 5a indicates the station coefficient obtained for the 77 JMA stations. Similar as the station coefficient for PGA, the station coefficient for the intensity is the largest for Kushiro station and the smallest for Matsushiro station. The weighted mean (with the number of records for each station used as weights) of the station coefficient is 0.182 for the intensity. The distribution of the JMA station coefficients with respect to the four soil types is shown in Fig. 5b.

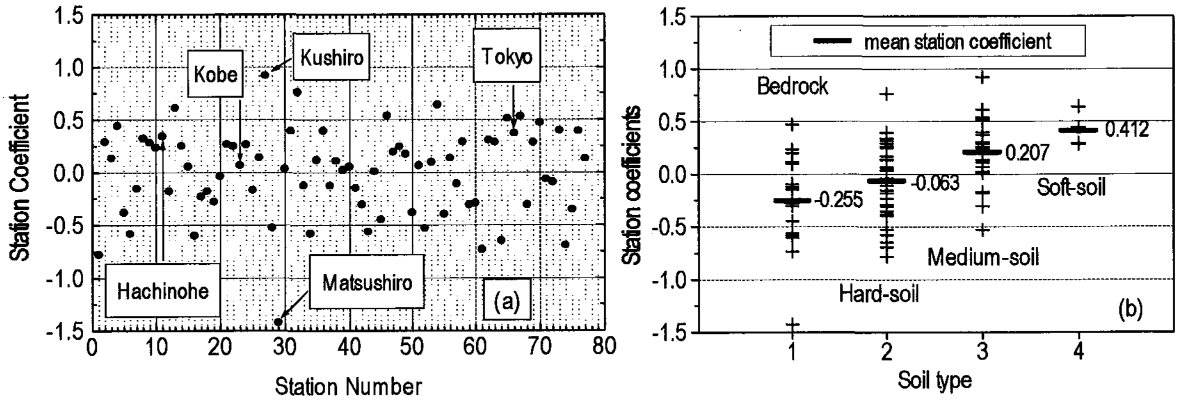


Fig. 5 Station coefficients for JMA intensity for (a) 77 JMA recording stations and (b) with respect to the soil type classification of JMA stations

The mean station coefficient for each soil type is given by the horizontal line. The station coefficients increase as the soil becomes softer.

Figure 6 shows the predicted JMA intensity with respect to the distance for depth of 10 km and magnitudes of 6.0, 7.0 and 8.0 (solid lines), and also the result for the data set B (dash lines). The weighted mean station coefficients (0.182) is used for the plot. The maximum predicted intensity for the magnitude 8.0 event is around 6.0 at the shortest distance of 20 km. Variability of station coefficient (see Fig. 5a) indicates that depending on sites, the predicted intensity becomes much larger (as large as about 0.92 for Kushiro). It should be noted that although the current data set includes some near-source records, the near-source saturation effect (Campbell, 1981) is not considered in the attenuation model. Hence, the current model should not be used for estimation of intensities at near fields. The proposed attenuation model is examined in Fig. 7 for three large earthquakes in the data set: the 1993 Kushiro-Oki, the 1994 Sanriku-Haruka-Oki and the 1995 Hyogoken-Nanbu Earthquakes.

Table 2 Regression coefficients for JMA intensity

data	b_0	b_1	b_2	b_3	b_4	σ_r	σ_e	σ
A	-0.087	1.053	-0.00256	<u>-1.89</u>	0.00496	0.459	0.224	0.511
B	-0.405	1.106	-0.00273	<u>-1.89</u>	0.00513	0.451	0.223	0.506

Underlined values are constrained

In the Figure 7, the solid line represents the predicted attenuation relation, open circles are intensities calculated from the records, and plus symbols are adjusted intensities removing site effects (station coefficients). It is observed that the adjusted intensities are much closer to the predicted curves than the recorded ones. It is noticed that the near-source saturation effect should be considered in the attenuation model for near field data (e.g. Fig. 7c, Fukushima and Tanaka, 1990). We are currently working on this issue and results will be presented in the near future.

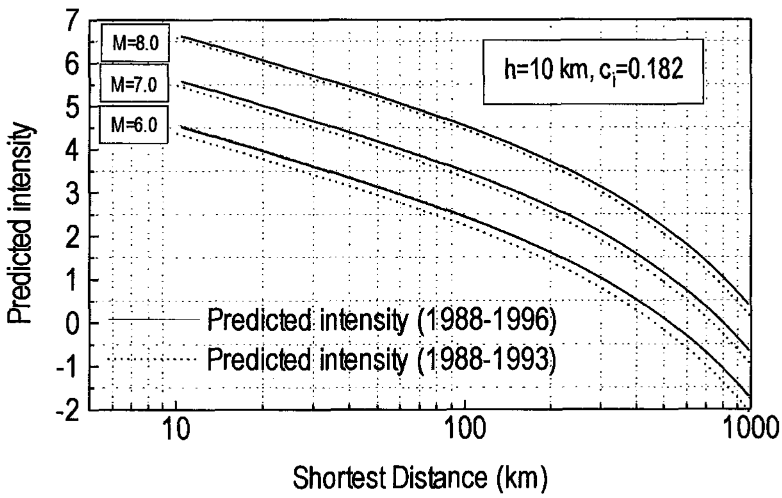


Fig. 6 Predicted JMA intensity for JMA magnitude of 6.0, 7.0, and 8.0 for depth of 10 km with mean weighted station coefficient 0.182

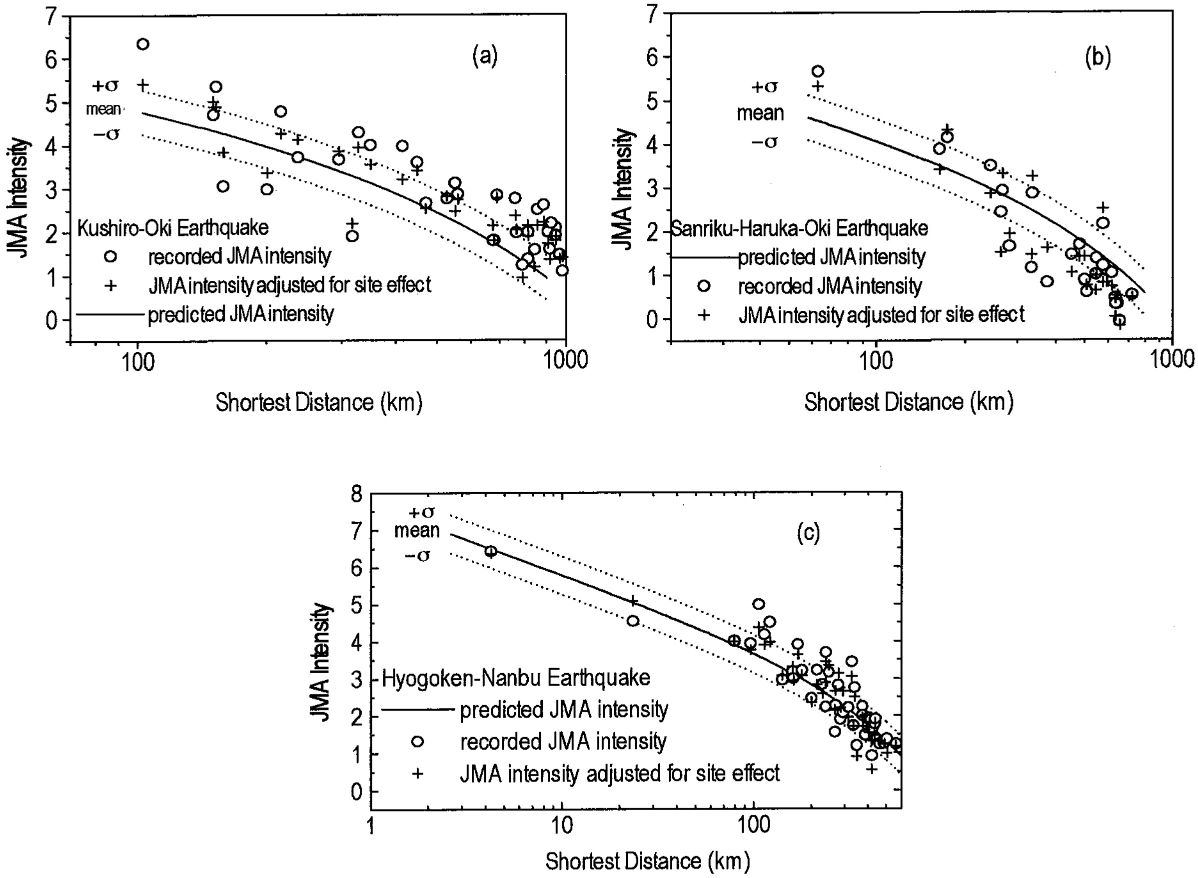


Fig. 7 Predicted JMA intensity by the attenuation relation compared with recorded intensities and adjusted intensities in three large magnitude events

CONCLUSIONS

An attenuation relationship was developed for the JMA seismic intensity using the 3,990 three-component records from the JMA-87-type accelerometers. The attenuation model proposed by Molas and Yamazaki for the peak ground acceleration and velocity was employed for the intensity attenuation. The three-stage iterative regression analysis gave the coefficients for the intensity. Local site effects was considered by the station coefficient. The obtained attenuation model was examined by recorded data in three large magnitude events. Since the near source saturation effect is not considered in the proposed model, the application of the model should be limited to intermediate to far field events.

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REFERENCES

Annaka, T., F. Yamazaki, and F. Katahira (1997). "Attenuation relations for peak ground motion and response spectra using JMA records", *Proc. of the 24th JSCE Earthquake Engineering Symposium*, Vol. 1, 161-164, (in Japanese).

Campbell, K.W. (1981). "Near-source attenuation of peak horizontal acceleration", *Bulletin of the Seismological Society of America*, Vol. 71, No.6, 2039- 2070.

Fukushima, Y. and T. Tanaka (1990). "A new attenuation relation for peak horizontal acceleration of strong ground motion in Japan", *Bulletin of the Seismological Society of America,* Vol. 80, No.4, 757-783.

Japan Meteorological Agency (JMA) Report, (1996). "Note on the JMA seismic intensity", *Gyosei,* (in Japanese).

Joyner, W. and D. M. Boore (1979). "Peak horizontal acceleration and velocity from strong-motion records including records from the 1979 Imperial Valley California earthquake", *Bulletin of the Seismological Society of America,* Vol. 71, 2011-2038.

Molas, G. L. and F. Yamazaki (1995). "Attenuation of earthquake ground motion in Japan including deep focus event", *Bulletin of the Seismological Society of America,* Vol. 85, 1343-1358.

Tong, H. and F. Yamazaki (1996). "Relationship between ground motion indices and new JMA seismic intensity", *Seisan-Kenkyu,* Vol. 48, No.11, (in Japanese).

Yamazaki, F. (1996). "Earthquake monitoring and real-time damage assessment systems in Japan-Developments and future directions", *Proc. from the 6th U.S.-Japan Workshop on Earthquake Resistant Design of Lifeline Facilities and Countermeasures Against Soil Liquefaction,* Technical Report NCEER-96-0012, 727-740.