Proceedings of the 9th U.S. National and 10th Canadian Conference on Earthquake Engineering
Compte Rendu de la 9ième Conférence Nationale Américaine et
10ième Conférence Canadienne de Génie Parasismique
July 25-29, 2010, Toronto, Ontario, Canada • Paper No 679

EARTHQUAKE GROUND MOTION INDICES FOR EARLY DAMAGE ESTIMATION OF WOODEN HOUSES IN JAPAN

S. Hoshi[1] , Y. Maruyama[2] and F. Yamazaki[3]

ABSTRACT

Earthquake motion indices play an important role in estimating damages due to ground shaking, and they are expected to be highly correlated with actual earthquake damages. However, there are some cases when building damages cannot be explained only by earthquake motion indices as in recent earthquakes. Therefore, this study evaluates the correlations between earthquake motion indices and building damage ratios performing seismic response analyses using numerical models of typical Japanese wooden houses. To obtain higher correlations, the spectrum intensity (SI) is recalculated by changing the damping ratio and the range of periods for an integration process. As a result, the period range to calculate a SI value should be selected properly to obtain higher correlation with wooden houses damage in Japan.

Introduction

An earthquake motion is expressed by various indices, e.g., seismic intensity, peak ground acceleration (PGA), peak ground velocity (PGV) and spectrum intensity (SI). Earthquake motion indices are used to estimate damages due to ground shaking (e.g. Molas and Yamazaki 1995, Karim and Yamazaki 2001). Therefore, it is expected that the correlations between earthquake motion indices and seismically-induced damages are high. That is also important for the sake of early damage estimation.

Building damage due to disaster incidents can affect human lives. During the 1995 Kobe earthquake, about 240,000 buildings were completely or partially collapsed and many people died because of the collapsed buildings (Architectural Institute of Japan 1996).

Recently, it has been pointed out that the correlation between seismic indices and damage ratios of buildings is relatively low. In 1996, the Japan Meteorological Agency (JMA) defined its seismic intensity to be obtained numerically (JMA 1996). Considering the change of various kinds of circumstances during the decade, the JMA revised the explanation table on its seismic intensity scale on March 31, 2009 (JMA 2009).

This study evaluates the correlations between earthquake motion indices and building damage ratios by performing seismic response analyses using numerical models of typical

[1]Graduate Student, Dept. of Urban Environment Systems, Chiba University, Japan.
[2]Associate Professor, Dept. of Urban Environment Systems, Chiba University, Japan.
[3]Professor, Dept. of Urban Environment Systems, Chiba University, Japan.

Japanese wooden houses. The seismic indices employed in this study are the JMA seismic intensity (I_{JMA}), PGA, PGV, and SI (Katayama et al. 1988). Many strong motion records obtained from recent earthquake events are used as input ground motions. The relationships between the seismic indices and the ductility factors of numerical models are evaluated. The SI is recalculated by changing the damping ratio and the range of periods for an integration process to be more correlated with the building damages.

Seismic Response Analysis of Typical Wooden Houses in Japan

In this study, 51 ground motion records from 14 earthquake events were selected as input motions. These ground motions were recorded by Kyosin-Network (K-NET), the Japan Meteorological Agency (JMA), and different municipalities in Japan. Single degree-of-freedom (SDOF) system was employed to perform series of seismic response analyses and the ground accelerations to horizontal directions were applied to the numerical model.

Typical Japanese wooden houses were modeled by the SDOF system with the initial elastic period, T_1. T_1 was set to be 0.1-1.0 s and the seismic coefficient, Y_1, was assigned as shown in Fig. 1 (Kanagawa Prefecture, Japan 1993). The damping ratio was set to be 5 % in the analyses.

As for the relationship between restoration force and displacement, a two-stage bi-linear model was employed as depicted in Fig. 2. The ductility factor, μ, was defined as the ratio between the maximum displacement, $\delta_{U,}$ and the yield displacement, δ_{Y2}.

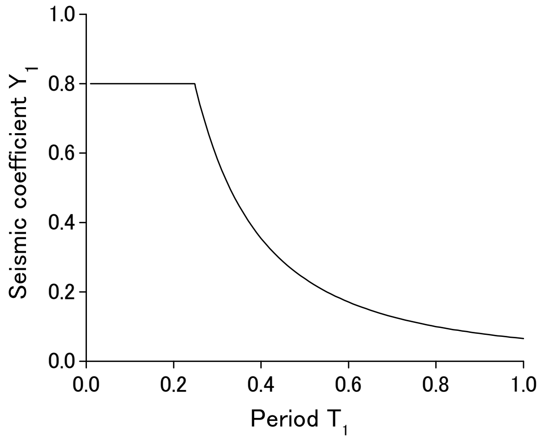

Figure 1. Relationship between the initial elastic period, T_1 and the seismic coefficient, Y_1.

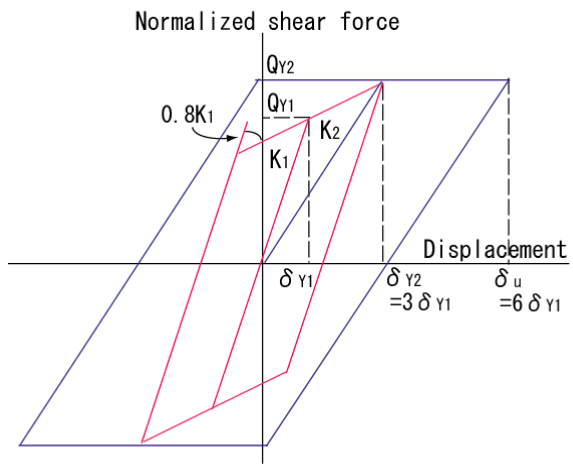

Figure 2. Two-stage bi-linear model presenting the relationship between the restoration force and displacement.

Relationship between Earthquake Motion Indices and Ductility Factors

Figure 3 shows the analytical result under the K-NET Anamizu record (EW comp.) in the 2007 Noto-Peninsula earthquake. PGA is 781.7 cm/s^2 and PGV 95.0 cm/s. The actual damage ratio of wooden houses was reported to be 18.8% (Sakai 2008). According to the numerical result, larger ductility factors are observed when the initial periods, T_1, are set to be longer than 0.4 s.

Figure 4 shows the relationships between earthquake motion indices and the

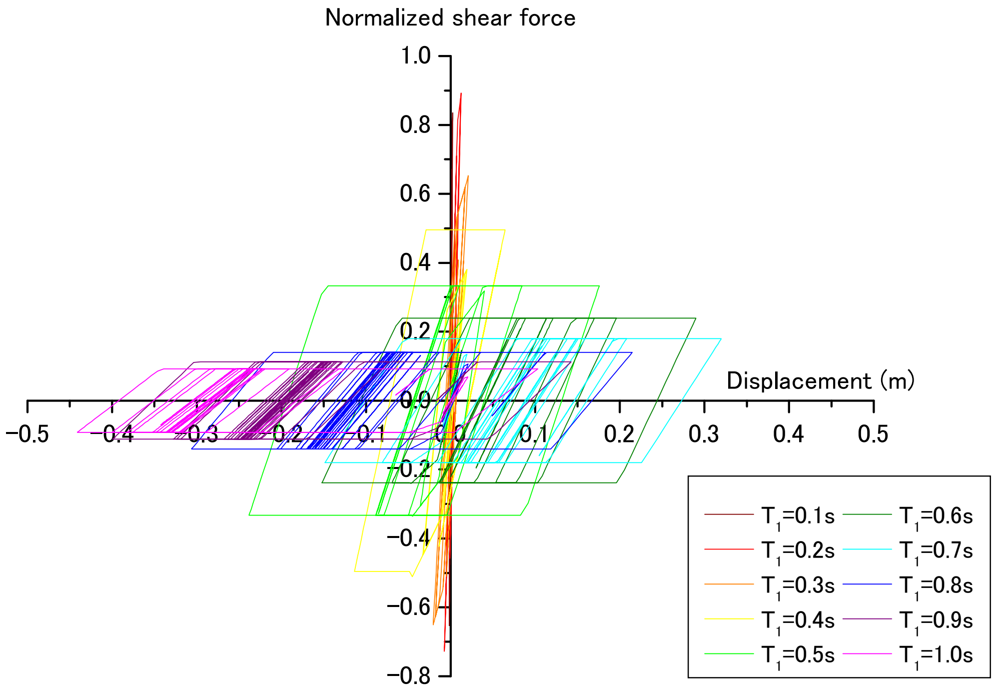

Figure 3. Relationship between the displacements of SDOF systems and the normalized restoring forces under the K-NET Anamizu record (EW) in the 2007 Noto-Peninsula earthquake.

ductility factors when the T_1 was set to be 0.3 s. The correlation coefficients r between the ductile factors and seismic indices are calculated by a linear regression analysis for all the results obtained under different initial elastic periods as shown in Fig. 5. The correlation coefficients with respect to PGA show higher values when the initial elastic periods of wooden houses were set to be 0.1-0.3 s. The PGV and SI are highly correlated with the ductility factors of the wooden houses with longer initial periods. The I_{JMA} seems to be correlated with the ductility factors up to some extent regardless of the initial elastic periods.

Generally, an initial period of wooden houses ranges from 0.1-0.5 s. Old houses are associated with longer initial periods (Sakai and Iizuka 2009), and old houses tend to be more vulnerable to extensive damage than the new ones. Hence, this study focuses the SI as an index to be highly correlated with the damages to wooden houses by changing the process of calculation.

Relationship between SI and Ductility Factors

The Spectrum Intensity is calculated through integration of velocity response spectrum (S_V) with the 20 % damping ratio for the structural periods between 0.1 and 2.5 s as shown in Eq. 1 (Katayama et al. 1988). The SI is employed in seismic safety control of urban gas supply systems (Shimizu et al. 2006) and traffic control of trains after earthquakes in Japan (East Japan Railway Co. 2005).

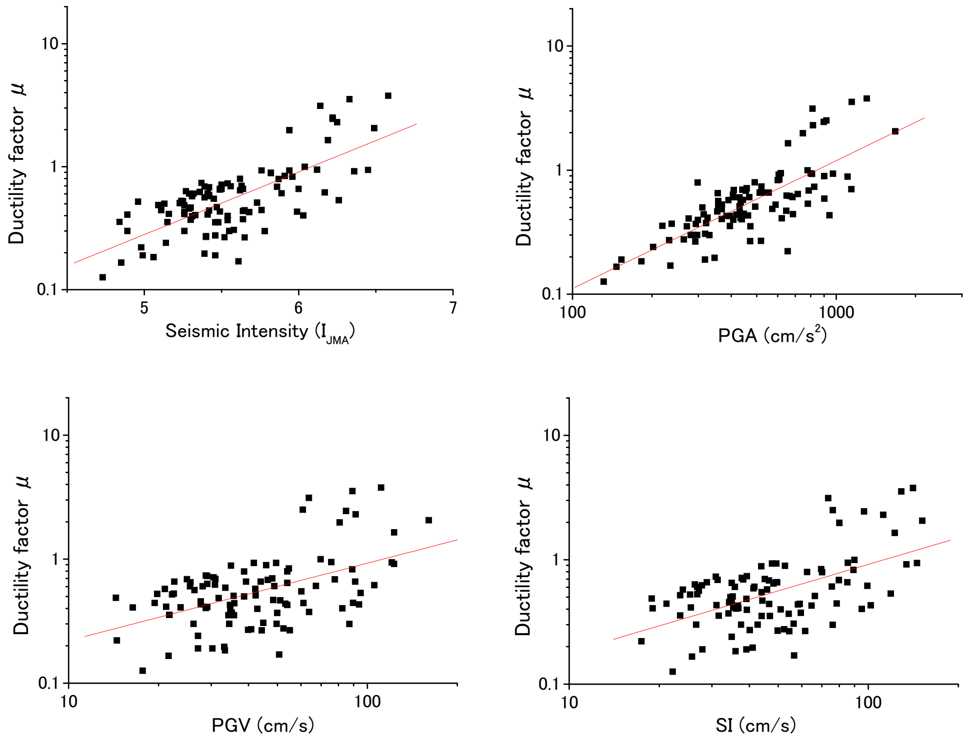

Figure 4. Relationship between the four earthquake motion indices and the ductility factors when the initial elastic period is set to be 0.3 s.

$$SI = \frac{1}{2.4}\int_{0.1}^{2.5} S_V(T)dT \qquad (1)$$

To obtain higher correlation with the ductility factors of wooden houses, the SI is calculated by changing the damping ratio, *h*, and the range of periods for integration, T_a - T_b, defined by Eq. 2. The damping ratios were set to be three cases: 0.05, 0.1, and 0.2. The ranges of periods are set to be five cases: 0.1-1.0 s, 0.1-1.5 s, 0.5-1.5 s, 0.5-2.0 s, 1.0-2.0 s, 1.0-2.5 s, and 0.1-2.5 s. Then a total of twenty one (21) SI values can be obtained by changing the damping ratio and the period range for integration.

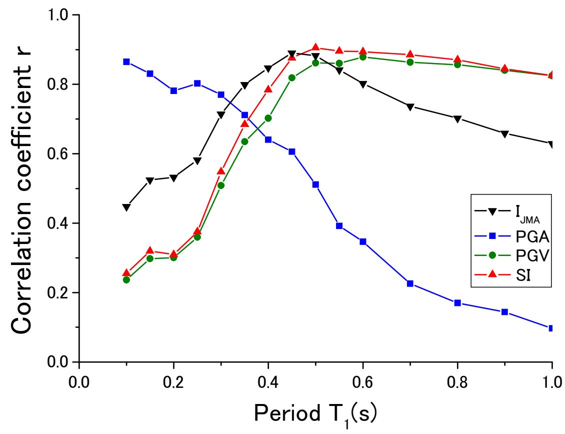

Figure 5. Relationship between the correlation coefficients and initial elastic periods of numerical models.

$$SI(h,T_a,T_b) = \frac{1}{T_b - T_a}\int_{T_a}^{T_b} S_V(h,T)dT \qquad (2)$$

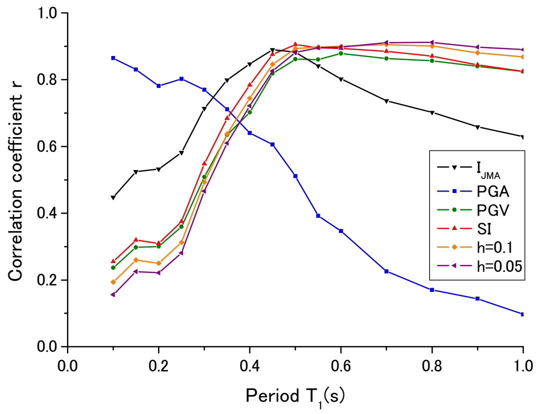

Figure 6. Relationship between correlation coefficients and the SIs with different damping ratios. The range of the periods for the SIs is set to be 0.1-2.5 s.

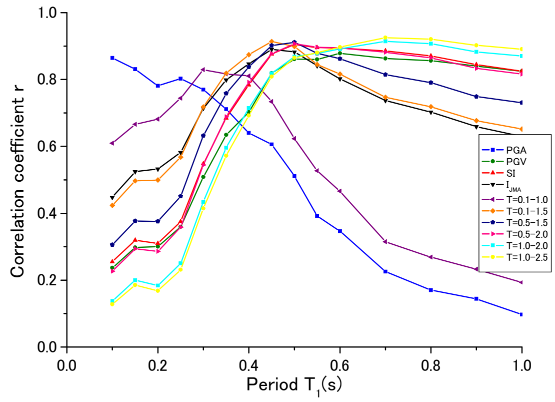

Figure 7. Relationship between correlation coefficients and the SIs with different ranges of periods for integration. The damping ratio is set to be 0.2.

The relationships between the correlation coefficients with respect to the SIs are shown in Figs. 6 and 7. Change in the damping ratio has not significant effect on the correlation coefficients as seen in Fig. 6. Hence, the period range for integration should be taken into account to show a higher correlation coefficient with wooden houses damage, instead of changing the damping ratio for the SI.

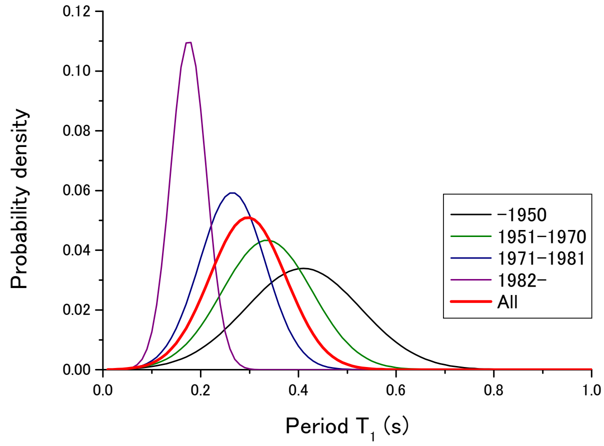

Figure 8. Probability density functions for the initial elastic periods of wooden houses with respect to the construction periods.

Relationship between Earthquake Motion Indices and Building Damage Ratios based on Numerical Simulation

Building damage ratios were numerically obtained assuming the distribution of initial elastic periods of wooden houses with respect to the construction periods. The mean and standard deviation of initial periods of wooden houses were assigned with respect to the construction periods (Sakai and Iizuka 2009), assuming to follow a normal distribution (Fig. 8). The numbers of wooden houses with respect to the construction periods were set to be proportional to those in Chiba Prefecture, Japan (2009). The wooden houses were assumed to be seriously damaged if the ductility factor becomes larger than 2.0 in the seismic response analysis.

Damage ratios were estimated using numerical models with various initial elastic periods, T_1 as shown previously. The damage ratio was assumed to follow a log-normal distribution with respect to each seismic index as shown in Fig. 9. The correlation coefficients were obtained

Table 1. Correlation coefficients between the damage ratio of wooden houses and various earthquake motion indices.

Correlation Coefficient *r*		Range of Period for Integration Process *Ta*～*Tb* (s)							Present Earthquake Motion Indices	
		0.1–2.5	0.1–1.0	0.1–1.5	0.5–1.5	0.5–2.0	1.0–2.0	1.0–2.5		
Damping Ratio *h*	0.2	0.607	0.653	0.761	0.697	0.616	0.501	0.470	I_{JMA}	0.774
	0.1	0.558	0.819	0.734	0.642	0.554	0.418	0.370	PGA	0.598
	0.05	0.535	0.816	0.722	0.610	0.519	0.369	0.346	PGV	0.514

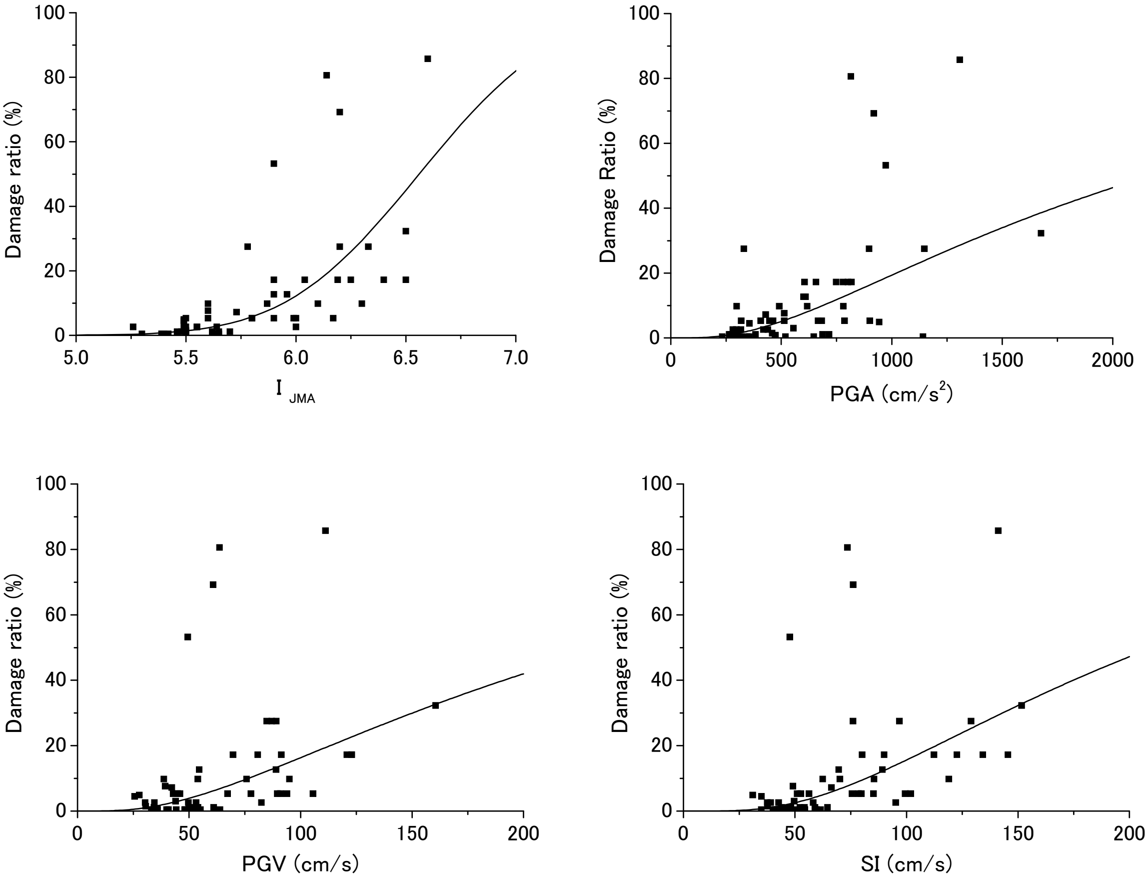

Figure 9. Relationships between the four seismic motion indices and damage ratios obtained by numerical simulation.

through the least-squares method on the log-normal probability paper (Yamaguchi and Yamazaki 2000). Table 1 shows the correlation coefficients with different period ranges for integration and damping ratios to obtain SI values. When the period for integration is set to be 0.1-1.0 s, the correlation coefficients show lager values.

Conclusions

This study evaluates the relationships between the earthquake motion indices and the building damage ratio by performing seismic response analyses using numerical models of typical Japanese wooden houses. According to the correlation coefficients between ductility factors and seismic motion indices, the SI and PGV gave better results considering the range of the initial elastic periods of fragile wooden houses in Japan.

The SI values were recalculated by changing the damping ratio and the period range for the integration process, to seek a higher correlation coefficient with the ductility factor. Through this numerical simulation, the period range for integration should be taken into account to show a higher correlation coefficient with wooden houses damage, instead of changing the damping ratio for the SI. Hence, the period range to calculate a SI value should be selected properly to obtain higher correlation with wooden houses damage in Japan.

References

Architectural Institute of Japan, 1996. *Report on the Damage Investigation of the 1995 Hyogoken-Nanbu Earthquake*.

Chiba Prefecture, Japan, 2009. *Report on the Damage Supposition Investigation of Earthquakes*.

East Japan Railway Co., 2005. http://www.jreast.co.jp/press/2005_2/20051020/no_3.html.

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

Japan Meteorological Agency, 2009. http://www.jma.go.jp/jma/index.html

Kanagawa Prefecture, Japan, 1993. *Report on the Damage Supposition Investigation of the Kanagawaken-Seibu Earthquake*.

Karim, K.R., F. Yamazaki, 2001. Effect of Earthquake Ground Motions to Fragility Curves of Highway Bridge Piers based on Numerical Simulation, *Earthquake Engineering and Structural Dynamics*, 30, 12, 1839-1856.

Katayama, T., N. Sato, K. Saito, 1988. SI-sensor for the identification of destructive earthquake ground motion, *Proceedings of the 9th World Conference on Earthquake Engineering*, 7, 667–672.

Molas, G.L., F. Yamazaki, 1995. Neural Networks for Quick Earthquake Damage Estimation, *Earthquake Engineering and Structural Dynamics*, 24, 4, 505-516.

Sakai, Y., and H. Iizuka, 2009. A Wooden House Cluster Model for Earthquake Damage Estimation by Nonlinear Response Analyses, *Journal of Japan Association for Earthquake Engineering* 9 (1), 32-45 (in Japanese).

Sakai, Y., S. Nojiri, T. Kumamoto, Y. Tanaka, 2008. Damage Investigation of Surroundings of the Seismic Station in the 2007 Noto-hanto Earthquake and Correspondence of Damage to Building with Strong Ground Motions, *Journal of Japan Association for Earthquake Engineering* 8 (3), 79-106 (in Japanese).

Shimizu, Y., F. Yamazaki, S. Yasuda, I.Towhata, T. Suzuki, R. Isoyama, E. Ishida, I. Suetomi, K. Koganemaru, and W. Nakayama, 2006. Development of Real-Time Safety Control System for Urban Gas Supply Network, *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, 132 (2), 237-249.

Yamaguchi, and F. Yamazaki, 2000. Fragility Curves for Buildings in Japan based on Damage Surveys after the 1995 Kobe Earthquake, *12th World Conference on Earthquake Engineering*, CD-ROM, 8p.