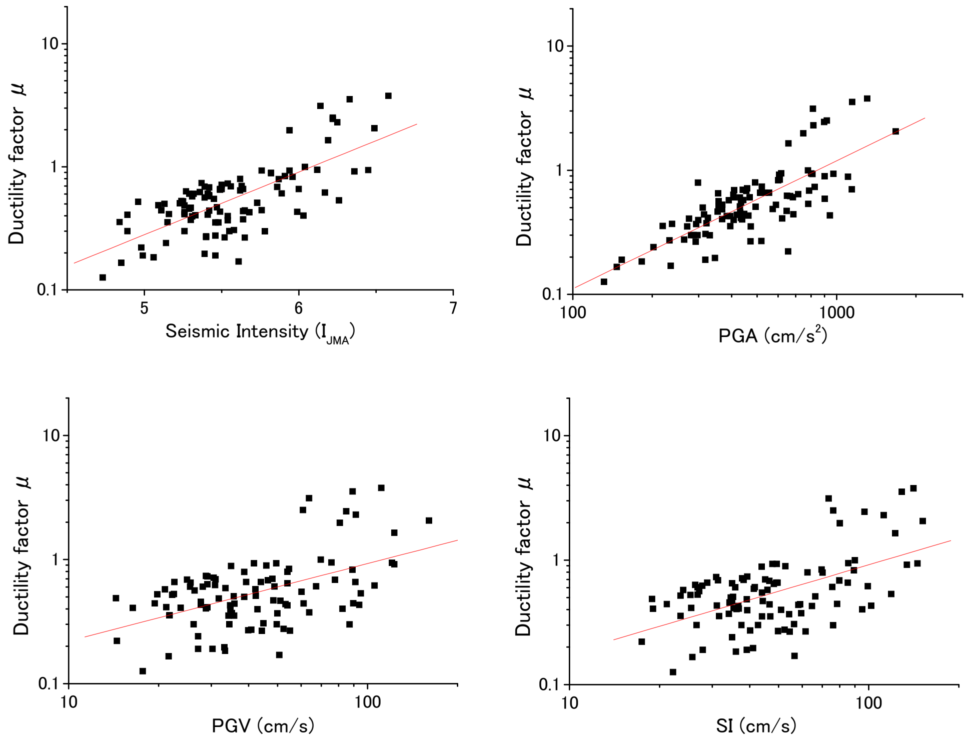

Figure 4. Relationship between the four earthquake motion indices and the ductility factors when the initial elastic period is set to be 0.3 s.

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

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.

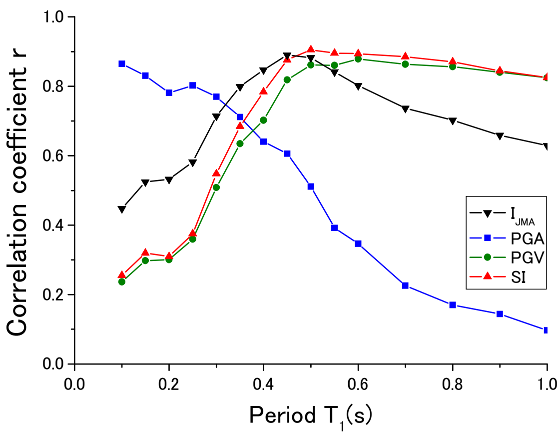

Figure 5. Relationship between the correlation coefficients and initial elastic periods of numerical models.

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

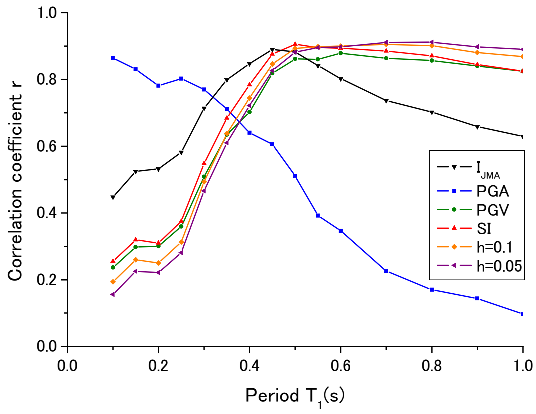

Figure 6. Relationship between correlation coefficients and the SIs with different damping ratios. The range of the periods for the SIs is set to be 0.1-2.5 s.

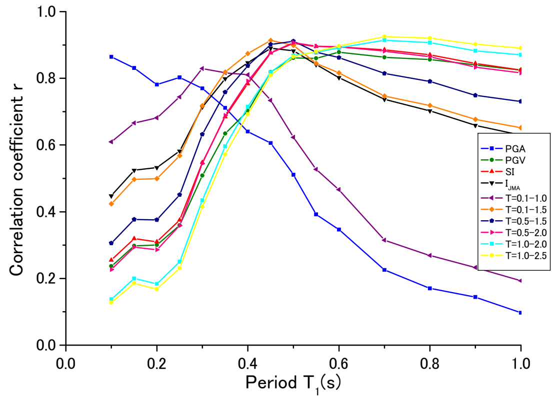

Figure 7. Relationship between correlation coefficients and the SIs with different ranges of periods for integration. The damping ratio is set to be 0.2.

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.

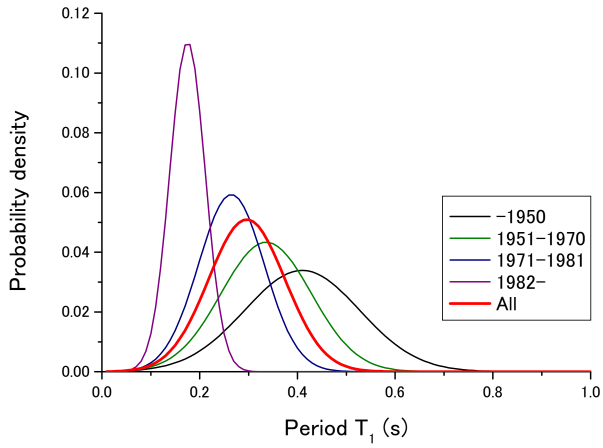

Figure 8. Probability density functions for the initial elastic periods of wooden houses with respect to the construction periods.

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

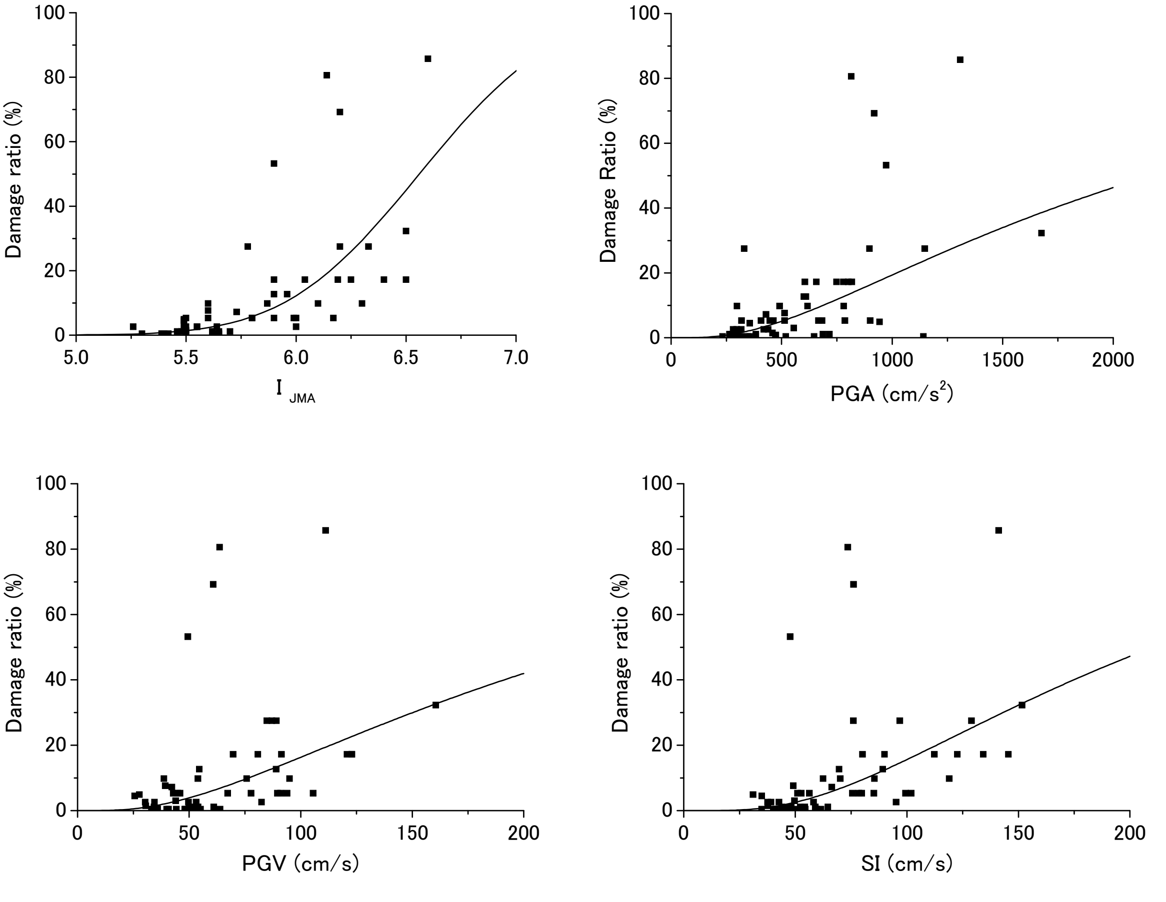

Figure 9. Relationships between the four seismic motion indices and damage ratios obtained by numerical simulation.

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.