13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 1255

COMPARATIVE STUDY ON WOODEN HOUSE DAMAGE BETWEEN 1995 KOBE EQRTHQUAKE AND 2000 TOTTORI EARTHQUAKE OF JAPAN

Yasuhiro HAYASHI[1]

SUMMARY

In this paper, the relations between construction years and damage ratio of wooden houses during the Hyogo-ken Nanbu earthquake and Western Tottori Prefecture earthquake are analyzed based on the damage statistics and evaluated PGVs. We have demonstrated quantitatively that not only the revisions of the Building Standard law but also the termite attack, decay and maintenance situation had affected the relation. In conclusion, to reduce the damage of wooden houses in big earthquakes to occur in the near future in Japan, it is inadequate to retrofit wooden houses with poor seismic performance although it is effective. The maintenance of houses by the owner and local carpenters after the retrofit (or construction) is also very important to hold the high seismic performance for a long term.

INTRODUCTION

In Japan, the occurrence probability of 30 years after is expected to be 40 or 50% according to the long-term prediction of the Nankai earthquake or Tonankai earthquake, which are plate boundary type great earthquake in the Nankai Trough. Therefore, it is pressing need to perform the retrofit of existing wooden houses with poor seismic performance.

Many people were killed by the collapse of wooden houses in the Hyogo-ken Nanbu earthquake of 1995 (Kobe earthquake). Damage ratio of wooden houses increase as construction years becomes old. According to the experience of Kobe earthquake, it is important to promote the retrofit of old houses with poor seismic performance. However, is it sufficient to pointing out the danger of old wooden houses? Furthermore, is it appropriate to judge seismic performance by construction years? Answers to these questions are very important. Because, wooden houses built in 1981, which were relatively new and suffered no damage during the Kobe earthquake, will become about 50 years old in 30 years' time.

On the other hand, the damage ratio of old houses remains small in the Western Tottori Prefecture earthquake of 2000 (Tottori earthquake). Namely, it became clear that the relation between the damage ratio of wooden houses and construction years differs completely from that in the Kobe earthquakes. Thus, strategies for mitigating house damage will change fundamentally with differences in an

[1] Associate Prof., DPRI, Kyoto University, Japan, Email:hayashi@zeisei.dpri.kyoto-u.ac.jp

interpretation of the two earthquakes. Then, in this paper, the damage ratio functions, which is the relationship between the peak ground velocities and the damage ratios, obtained from the two earthquakes are compared, and the difference in the damage tendency is interpreted.

DAMAGE RATIO FUNCTION BASED ON THE 1995 KOBE EARTHQUAKE

The Hyogo-ken Nanbu earthquake of 1995 (Kobe earthquake) caused severe damage to Kobe city and the surrounding area in Japan. It is an important and essential theme to clarify the seismic performance of damaged buildings during the Kobe earthquake.

First, the PGVs shown in Fig. 1 are calculated from the damage ratio of low-rise residential houses using the relationship between the damage ratios and the peak velocities of estimated ground motions in the most severely damage area, Sannomiya district. The estimated PGV distribution shows good correspondence with observed records and simulated ground motions by other researchers. The PGVs ranges from 100 cm/s to 150 cm/s in the most heavily damaged area. Then, we have developed vulnerability functions of various types of buildings relating peak ground velocities (PGVs) to their damage ratios. In this paper, the damage ratio functions are obtained from the PGVs and damage data of wooden houses suffering proof published by local government. The damage ratio functions classified by construction years of the wooden houses (Miyakoshi et. al. (1997)) are shown in Fig. 2. Figure 2 (a) and (b) correspond to the damage of half destroyed and completely destroyed houses, respectively. The tendency for the damage ratio, which increases as construction years, becomes old in the Kobe earthquake, can be confirmed clearly.

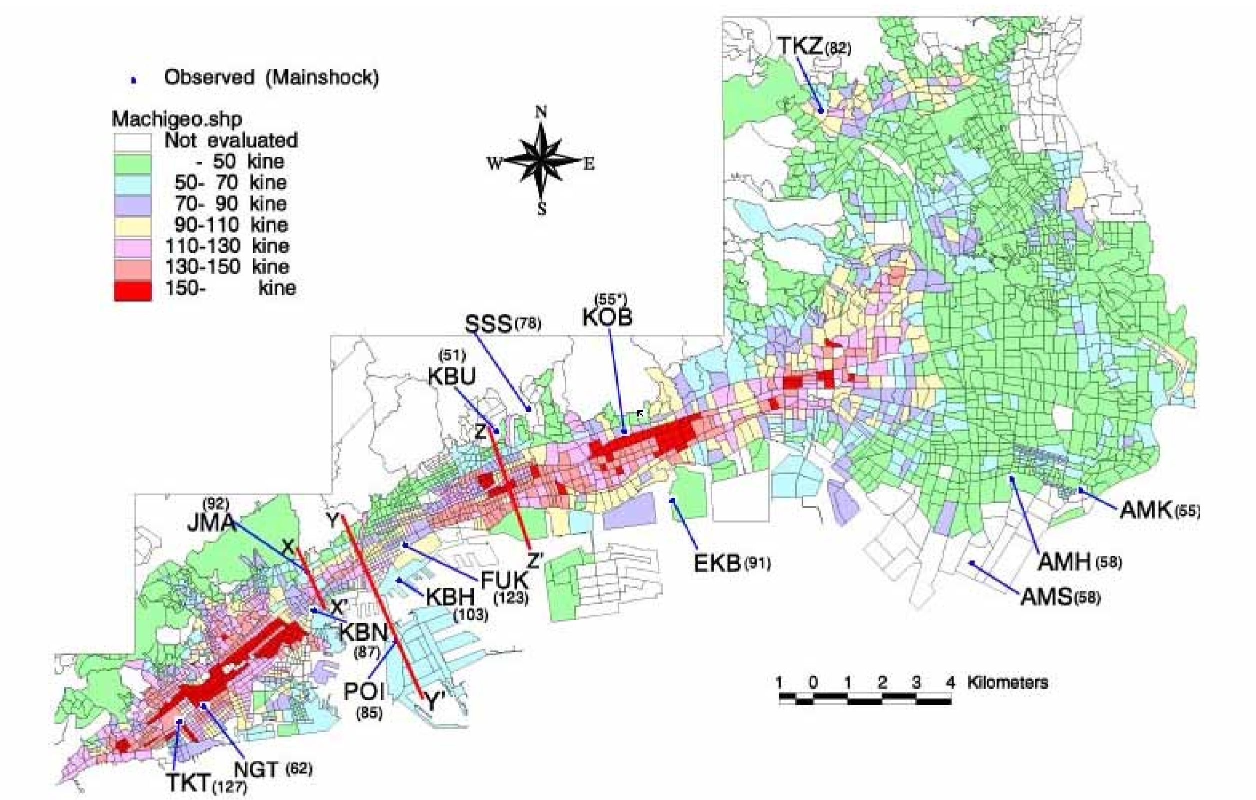
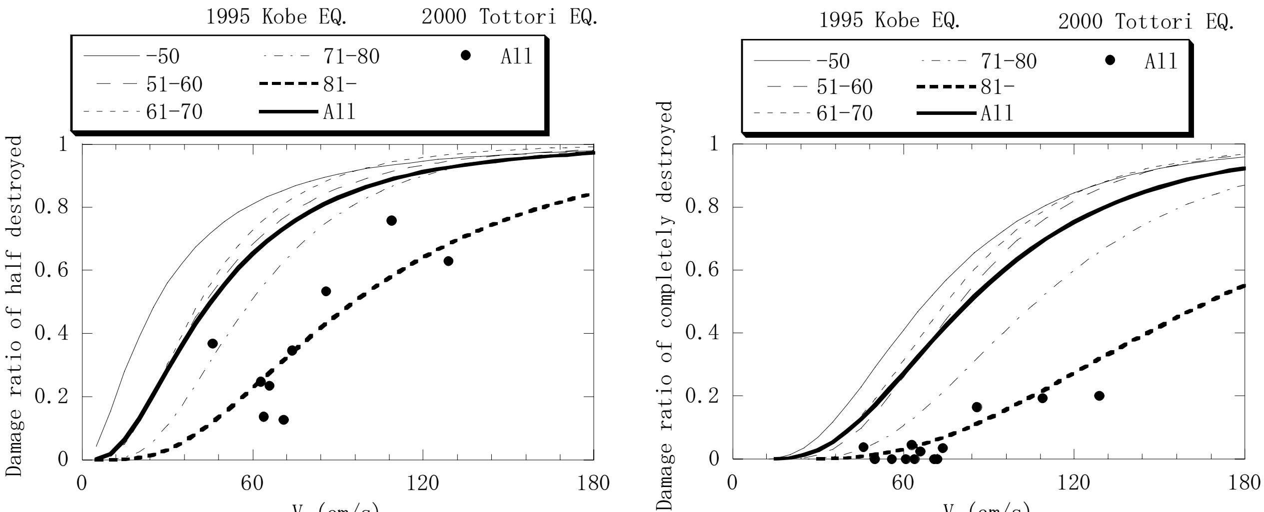


Figure 1 Evaluated PGV distribution (Y.Hayashi et.al. (1997))



(a) Half or completely destroyed (b) Completely destroyed

Figure 2 Comparison of damage ratio functions based on the Kobe EQ. and Tottori EQ.

DAMAGE RATIO FUNCTIONS OF THE 2000 TOTTORI EARTHQUAKE

Figure 3 shows the location of Hino town where many wood houses suffered extensive damage during the Western Tottori Prefecture earthquake of 2000 (Tottori earthquake). The Hino town is located in the southwest part of Tottori prefecture and very close to the epicenter of the earthquake. The Hino town is a town of a place between mountains and steep mountains with an altitude from 700 to 1,100 m are pressing for it close at hand. According to the result of the national census in the 2000 fiscal year, population is 4,517 and the number of households is 1,549.

Figure 4 shows the acceleration response spectra of typical records observed at the JMA (Japan Meteorological Agency) Kobe station during the Kobe earthquake and TTRH02 station of KiK-net by the NIED (National Research Institute for Earth Science and Disaster) during the Tottori earthquake. Both stations are located around the most heavily damaged area during the Kobe earthquake or Tottori earthquake. As you can see easily from the figure, the difference in the two spectra is not so large. Although a lot of seismic motions were recorded in wide area during the Tottori earthquake, no record except for that at the TTRH02 station was observed in the epicentral region.

Therefore, we estimated the PGVs from the ratios of toppled tombstones in order to grasp the distribution of seismic ground motion intensity around the epicentral region (Hayashi et.al. (2001)). In the estimation, we used the relation between PGVs and the overturning ratios developed by Kaneko and Hayashi (2000). The distribution of the PGVs along the direction (almost SW-NE direction) which intersected perpendicularly with the fault line is shown by broken line in Fig. 5. The peak velocities of records at TTR007 and TTR009, where are K-NET stations also installed by the NIED and 10 to 15 km apart from the fault line, show good agreement with estimated PGVs. The damage ratio distribution is also depicted by solid line in the same figure. The PGVs varies in sync with the damage ratios, and drastically increase in the area which ranges from Kurosaka district to Yasuhara district. The PGVs amount to not less than 80 cm/s in the most heavily damaged area, and is almost comparable with those estimated in the heavily damaged area during the Kobe earthquake.

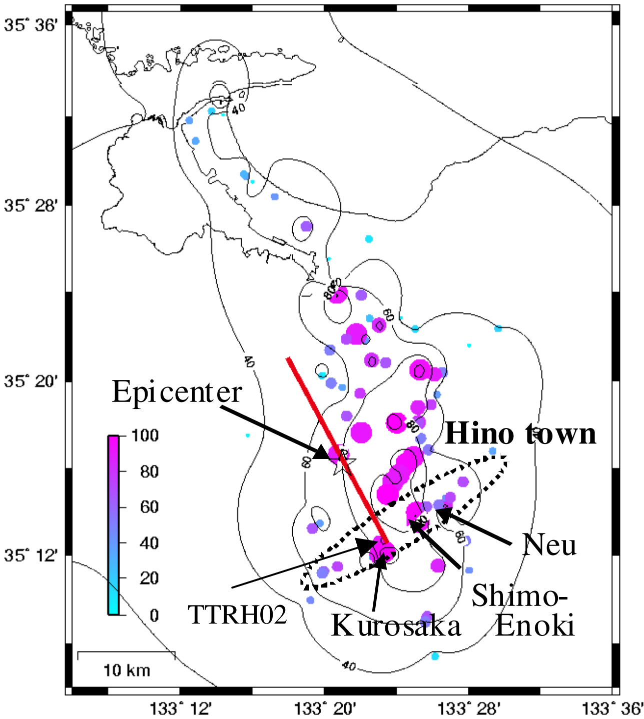


Figure 3 Estimated PGV distribution from overturning ratios of tombstones in the 2000 Tottori EQ. (Hayashi et.al. (2001))

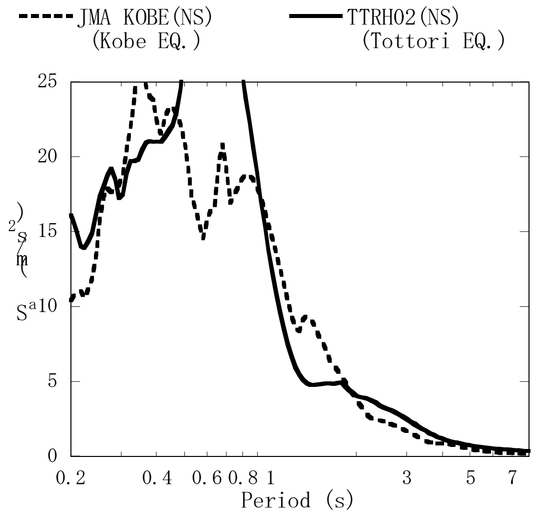


Figure 4 Acceleration response spectra of typical records in the two earthquakes

Next, the variation in damage ratio with construction years of the wooden houses is compared between the two earthquakes. The variation in Ashiya city during the Kobe earthquake is shown in Fig. 6 (a). The tendency for the ratio of completely destroyed houses in Ashiya city to increase remarkably as construction years become old can be easily recognized. Figure 6 (b) shows the relation between construction years and the damage ratio in Hino town. Unlike the damage tendency in case of the Kobe earthquake, even if construction years becomes old such as 100 to 200 years ago, the damage ratio of completely destroyed house is not increasing so much.

Then, the relation of the estimated PGVs and the damage ratios are shown in Fig. 2 by solid circle symbols and it is compared with the damage ratio function obtained from the Kobe earthquake. Although the damage ratio function in the Tottori earthquake is not classified by construction years, it corresponds to that for houses build after 1981. It can be said that the seismic performance of old wooden houses in Hino town was equal to that of houses designed in accordance with the current Building Standard Law. The reasons for this is considered as follows (Kitahara et.al.(2002)).

1) Wooden materials and members used for houses is very good since they are local products.
2) Technique of local carpenters is excellent.
3) Local carpenters and owners maintain houses frequently and adequately.

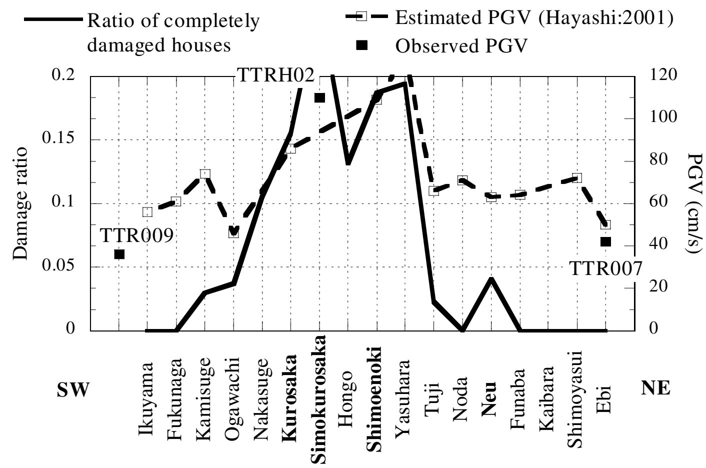
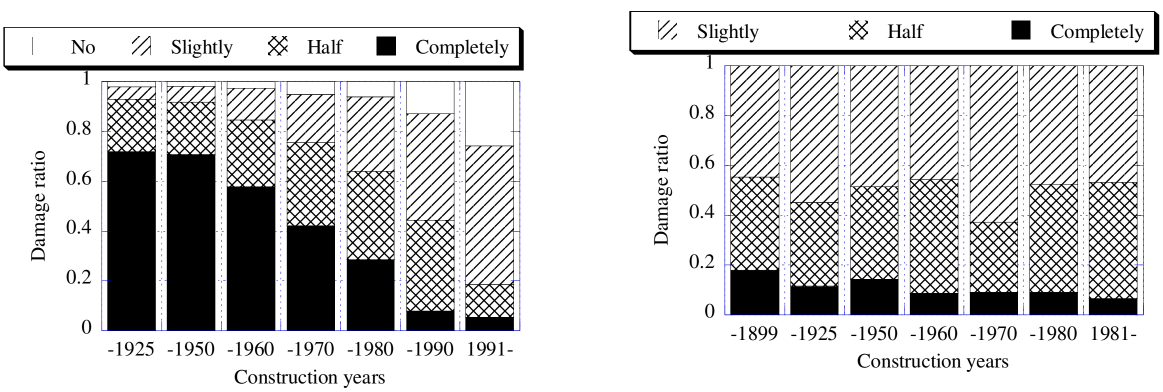


Figure 5 Comparison between PGVs and completely damage ratios in 2000 Tottori EQ.
(Hayashi et. al. (2001))



(a) 1995 Hyogo-ken EQ. (Ashiya-city) (b) 2000 Western Tottori Prefecture EQ.(Hino town)

Figure 6 Variation of damage ratios with construction years

INFLUENCE OF BIODETERIORATION IN THE KOBE EARTHQUAKE

It is said that the influence of biodeterioration such as decay and termite attack becomes large as construction years become old. Doi and Miyano (1998) investigated the influence of biodeterioration on the damage of wooden houses for an area in Kobe city. We investigate the influence of decay and termite attack on the damage of wooden houses quantitatively in the followings. After distinguishing the existence of decay and termite attack, the relations of construction years and damage ratio are shown in Fig. 7. If the existence of biodeterioration can be identified, construction years have not influenced greatly to the ratio of completely destroyed houses. If biodeterioration was found, the ratios of completely destroyed houses are not less than 90%. Otherwise, the damage ratios are less than 40%.

Next, influence of biditerioration on the damage ratio functions classified by construction years is investigated. The damage ratios shown in Fig. 7 are related to the estimated PGV of 165 cm/s for the investigated area using Fig. 1. The relations are depicted in Fig. 8. The ratios of completely destroyed houses without biodeterioration are less than that for the houses built after 1981 regaedless of construction years. That is, the influence of construction years on earthquake damage is not so large for houses without biodeterioration in Kobe city as well as houses in Hino town damaged during the Tottori earthquake. Performance of houses without biodeterioration is not so bad even if they are old enough. In conclusion, to reduce the damage of wooden houses in big earthquakes to occur in the future, it is inadequate to retrofit wooden houses with poor seismic performance although it is effective. The maintenance of houses by the owner and local carpenters after a retrofit is also very important to hold the high seismic performance for a long term.

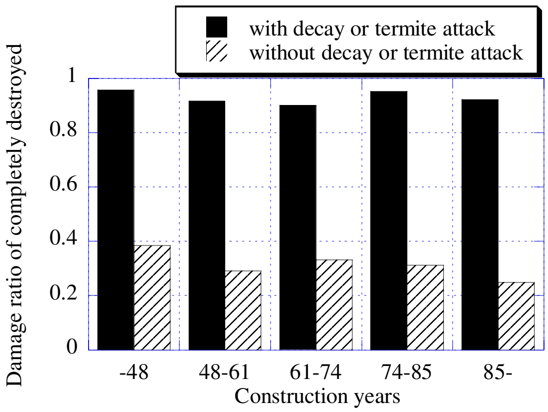


Figure 7 Variation of damage ratio with construction years

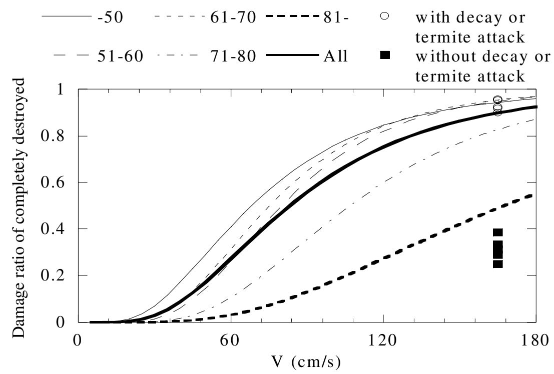


Figure 8 Damage ratio functions of houses with or without biodeterioration

CONCLUSIONS

The damage ratios of wooden house in the 2000 Western Tottori Prefecture earthquake (Tottori earthquake) are remarkably small compared with those in the 1995 Hyogo-ken Nanbu earthquake (Kobe earthquake). The purpose of our study is to clarify the cause of the difference in the seismic intensity of ground motions and damage ratios produced by two earthquakes in Japan.

First, in order to compare damage ratios in the two earthquakes at the same peak ground velocity (PGV) level, we have newly developed a relation between the PGV and damage ratio for the Tottori earthquake. At that time, since there are few seismic observation records in the source region of the Tottori earthquake, the PGVs are evaluated from the overturning ratios of tombstones.

As for the Kobe earthquake, the damage ratio of houses built more than 30 years ago is remarkably high compared with that of houses built within 20 years as pointed out by many researchers. As for the Tottori earthquake, however, the damage ratio of houses is hardly affected by construction years. Then, the damage ratios of houses in the Tottori earthquake are comparable to those of houses built after 1981 in the Kobe earthquake, even if houses built more than 100 years ago are included. This tendency is mainly due to the fact that local carpenters have carried out maintenance of houses frequently and adequately. As a proof of this reason, we show a quantitative data suggesting that if houses were not influenced by decay or termite attack, damage ratios would not have varied with construction years also in the Kobe earthquake.

In conclusion, to reduce the damage of wooden houses in big earthquakes to occur in the future, it is inadequate to retrofit wooden houses with poor seismic performance although it is effective. The maintenance of houses by the owner and local carpenters after the retrofit (or construction) is also very important to hold the high seismic performance for a long term.

REFERENCES

1. Hayashi, Y. , J. Miyakoshi and K. Tamura (1997) : Study on the Distribution of Peak Ground Velocity based on Building Damage during the 1995 Hyogo-ken Nanbu Earthquake, Eng., AIJ, No. 502. pp.61-68 (in Japanese).
2. Miyakoshi, J., Y.Hayashi and K.Tamura (1997) : Damage Ratio Functions of Buildings Using Damage Data of the 1995 Hyogo-Ken Nanbu Earthquake, Proc. of ICOSSAR'97, pp.349-354.
3. Hayashi,Y., A. Kitahara, T. Hirayama and Y. Suzuki.(2001) Evaluation of Peak Ground Velocities in Western Tottori Earthquake of 2000', J. Struct. Constr. Eng., AIJ, No. 548. pp.35-41 (in Japanese).
4. Kaneko, M. and Y. Hayashi (2000) : Proposal of a Curve to Describe Overturning Ratios of Rigid Boies, AIJ, No. 536. pp.55-62 (in Japanese).
5. Kitahara, A., Y. Hayashi, T. Okuda, Y. Suzuki and M. Goto (2002) Structural Characteristics and Earthquake Damage of Wooden Houses in the 2000 Western Tottori Earthquake, J. Struct. Constr. Eng., AIJ, No. 561. pp.161-167 (in Japanese).
6. Doi, T. and M. Miyano (1998) : Damage due to Decay and Termite attack, Investigation Report on the Hanshin-Awaji Great Earthquake, Part 4 of Building Edition, Wood Buildings, pp.198-205 (in Japanese).