PREDICTION OF DAMAGE TO WOODEN HOUSES

BY USING FATIGUE RESPONSE SPECTRA CONSIDERING THE NUMBER OF SEISMIC RESPONSE CYCLES

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SUMMARY

This study proposes an index for prediction of damage to wooden houses. Since the structures are affected by a fatigue damage, it is inevitable in predicting damage to structures to consider the number of seismic response cycles of the large seismic response. In this study, an index for predicting damage to wooden houses is proposed in taking account of number of seismic response cycles and the natural period of structures. This index, which is called as 'Fatigue response Spectral Intensity (*FSI* value)', is defined as integrated value on tripartite coordinates; natural period of wooden houses, pseudo-response velocity spectra and the number of seismic response cycles. In addition, existing probability of natural period of wooden houses is taking into account in this index.

This *FSI* value was calculated by using the data in the recent earthquakes in Japan such as the 1994 Hokkaido Toho-oki earthquake, the 1994 Sanriku Haruka-oki earthquake, the 1995 Hyogoken-Nambu earthquake and so on. This index was able to represent the damage to wooden houses more accurately than the alternative indices such as maximum acceleration and *SI* value.

INTRODUCTION

Recently, many destructive earthquakes have occurred in Japan. Especially, the 1995 Hyogoken-Nambu earthquake killed many people and damaged a lot of structures. One of main causes of this disaster was the collapse of wooden houses.

Generally, the maximum ground response acceleration and spectral intensity (*SI* value) have been used as the indices of prediction of damage to structures. Although the structures are affected by a fatigue damage, it is not considered in these indices. An index for predicting damage to wooden houses is defined by taking account the number of seismic response and the natural period of structures. In addition, existing probability of natural period of wooden houses is taking into account in this index.

The *FSI* value was calculated by using the data in the recent earthquakes such as the 1994 Hokkaido Toho-oki earthquake, the 1994 Sanriku Haruka-oki earthquake, the 1995 Hyogoken-Nambu earthquake and so on. Then the correlation between the *FSI* value and damage to wooden houses was investigated.

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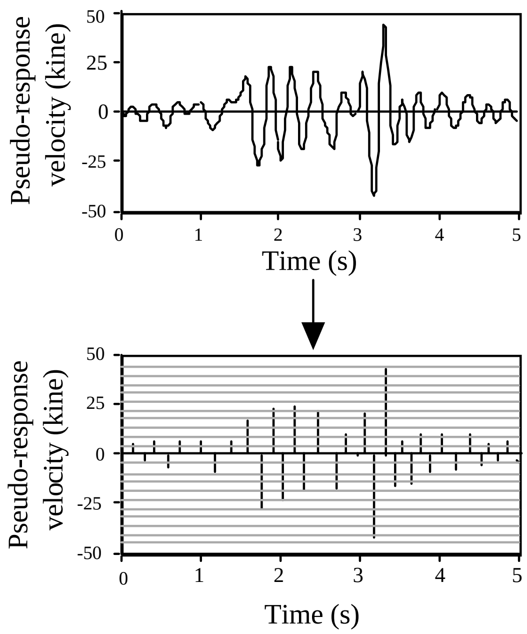

Figure 1: Transform of the response velocity wave

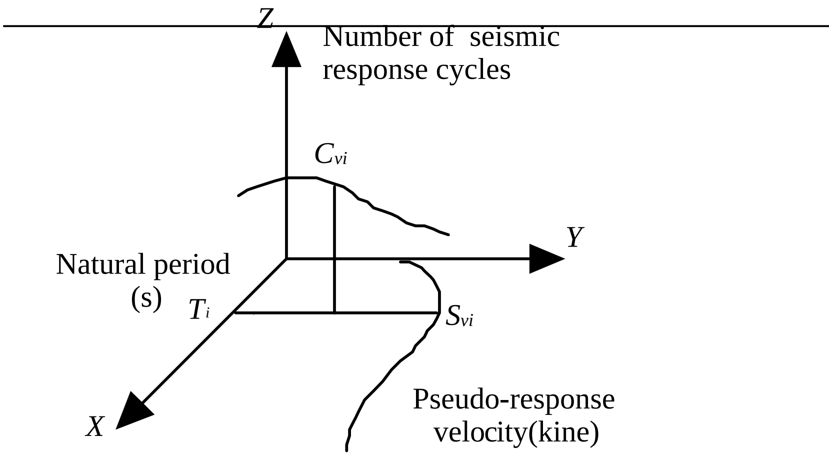

Figure 2: Concept of fatigue response velocity spectrum

A PROCEDURE OF ANALYSIS

Fatigue response spectral intensity (*FSI*)

An index for predicting damage to wooden houses is proposed here. This index is defined as integrated value on tripartite coordinates; natural period of wooden houses (T) as x-axis, pseudo-response velocity spectra (S_v) as y-axis and the number of seismic response cycles (C_v) as z-axis. The number of seismic response cycles was counted by using the bar graph of acceleration as shown in Figure 1. For the purpose of comparing with *SI* value , the natural period of wooden houses is considered as the ranges from 0.1(s) to 2.5(s), and damping ratio h is 0.05 in this section,. Figure 2 illustrates the concept of fatigue response velocity spectrum.

FSI value is given by the following equation.

$$FSI = \int_T \int_{S_v} C_v S_v^2 dS_v dT \qquad (1)$$

Existing probability of natural period of wooden houses

An existing probability of natural period of wooden houses is taking into account in this index. Generally, it is known that natural period of wooden houses takes the ranges from 0.1(s) to 0.8(s), and natural period is different from each house by stories, purposes of use and constructing age. The existing probability of natural period of wooden houses was estimated by taking account of these indices and was established the ranges in this section. Wooden houses were classified into six groups listed in Table 1 according to these indices. Figure 3 shows the existing probability of natural period of wooden houses for each group. The existing probabilities were assumed as normal distribution in this study. Figure 4 displays the existing probability of natural period of wooden houses considering the constructing ages (a_T). This probability was evaluated as the product of the natural period of wooden houses shown in Figure.3 and the existing probability of each group listed in Table 1. Equation (1) was modified as the following equation in taking a_T into account.

$$FSI' = \int_T a_T \int_{S_v} C_{S_v} S_v^{\,2} dS_v dT \tag{2}$$

This index is called as 'Fatigue response Spectral Intensity considering the constructing ages of wooden houses (*FSI'* value)'.

Table 1: Wooden houses classified by structures, stories, purposes, and constructing ages

Structure, Stories and Purpose of use	Non tile-roofed houses	Residential house (One-story)	Residential house (Two-stories) Non residential house (One-story)	Non residential house (Two-stories)	▪
	Tile-roofed houses	▪	Residential house (One-story)	Residential house (Two-stories) Non residential house (One-story)	Non residential house (Two-stories)
Constructing ages	~1950	1	1	1	1
	1951~1960	3	2	2	2
	1961~1970	4	4	4	3
	1971~1980	5	5	5	4
	1981~	6	6	6	5

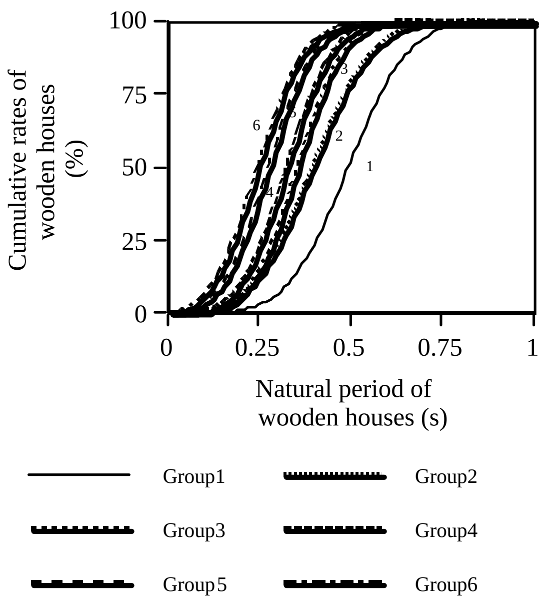

Figure 3: Existing probability of natural period of wooden houses for each group

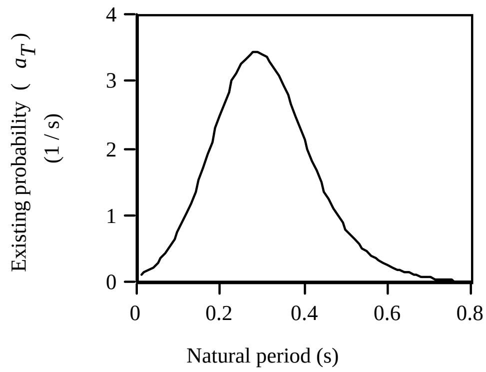

Figure 4: Existing probability of natural period of wooden houses considering the constructing ages

Table 2: Damage ratio of wooden houses in the analyzing areas

Earthquake name	Analyzing area	Damage ratio of wooden houses(%)
1993 Noto-Hanto-Oki earthquake	Wajima	0.05
1994 Hokkaido Toho-Oki earthquake	Nemuro	1.35
1994 Sanriku-Haruka-Oki earthquake	Hachinohe	0.17
1995 Hyogoken-Nambu earthquake	Kobe C.	12.20
Ditto.	(Chuo W.)	12.70
Ditto.	(Nada W.)	24.30
Ditto.	(Suma W.)	12.20
Ditto.	Amagasaki	1.30
Ditto.	Akashi	6.37
Ditto.	Takarazuka	4.50
1997 Kagoshimaken-Hokuseibu earthquake（May）	Izumi	0.00
	Miyanojyo	0.00
Ditto.	Sendai	0.00

ANALYTICAL RESULTS

In this chapter, maximum acceleration, spectral intensity (*SI*) and fatigue response spectral intensity (*FSI* and *FSI'*) were calculated and the relation was investigated between each index and damage to wooden houses. Damage to wooden houses was estimated by the damage ratio of wooden houses (*D*). Damage ratios of wooden houses in the target areas are listed in Table 2. This ratio is defined as the following equation.

$$D = \frac{D_1 + D_2/2}{h_a} \times 100 \qquad (3)$$

In which, D_1 is the amount of serious damaged houses, D_2 is the amount of medium damaged houses, h_a is the total amount of houses.

Maximum acceleration

Figure 5 shows relationship between the maximum acceleration and damage ratio of wooden houses. Coefficient of correlation r is 0.73. Coefficient of correlation was not so good because the damage ratios of Hachinohe, Izumi and Miyanojyo seemed to be too small in spite of the great maximum acceleration. The time histories of accelerations and fourier spectra for three sites are shown in Figure 6 and Figure 7, respectively. It was shown that the duration of strong accelerations in Hachinohe was short, and predominant frequencies in Izumi and Miyanojyo were high, that is over 10Hz. Although these characteristics affected the small damage ratio, these information were not included in the maximum acceleration. Therefore maximum acceleration was not enough to estimate the damage to wooden houses.

Spectral intensity (*SI*)

Figure 8 shows relationship between *SI* value and damage ratio of wooden houses. Coefficient of correlation r is 0.84. Damage ratio in Akashi seemed to be too great comparing the *SI* value. Figure 9 shows the time history of acceleration in Akashi city. The numbers of cycle of large acceleration were relatively great. Although this seemed to affect the great damage ratio, this effect did not include the *SI* value.

Fatigue response spectral intensity (*FSI*)

Figure 10 shows relationship between *FSI* value and damage ratio of wooden houses. Coefficient of correlation r is 0.90 and it is better than that of *SI* value. Thus it was clarified that *FSI* value was able to represent the damage more accurately than the alternative indices such as maximum acceleration and *SI* value. The relationship between *FSI'* value considered existing probability of natural period of wooden houses and damage ratio of wooden houses is shown in Figure 11. Coefficient of correlation r is 0.81 and it was not better than that of *FSI* value. Especially correlations of Nemuro and Hachinohe were not good. The existing probability of natural period of wooden houses in Kobe City (Hyogoken-Nambu Earthquake) is used in these cities because of no data concerning with the existing probability. It is considered that the existing probability of natural period of wooden houses in the two cities are very different from that in Kobe City. Figure 12 shows relationship between *FSI'* value and damage ratio of wooden houses for four cities in Kobe area (Kobe, Akashi, Amagasaki and Takarazuka). Coefficient of correlation r is 0.99 and it is better than those of any other indices. Thus the *FSI'* value was able to represent damages to wooden houses more accurately.

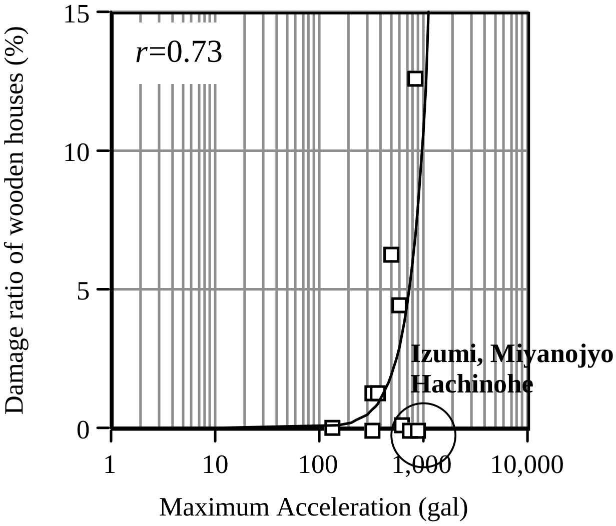

Figure 5: Relationship between maximum acceleration and damage ratio of wooden houses

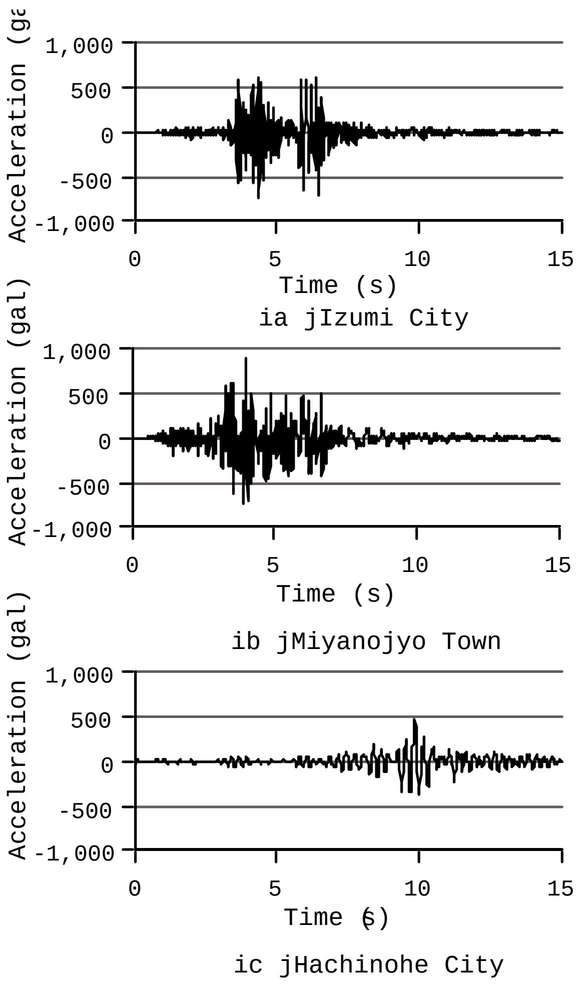

Figure 6: Time histories of accelerations

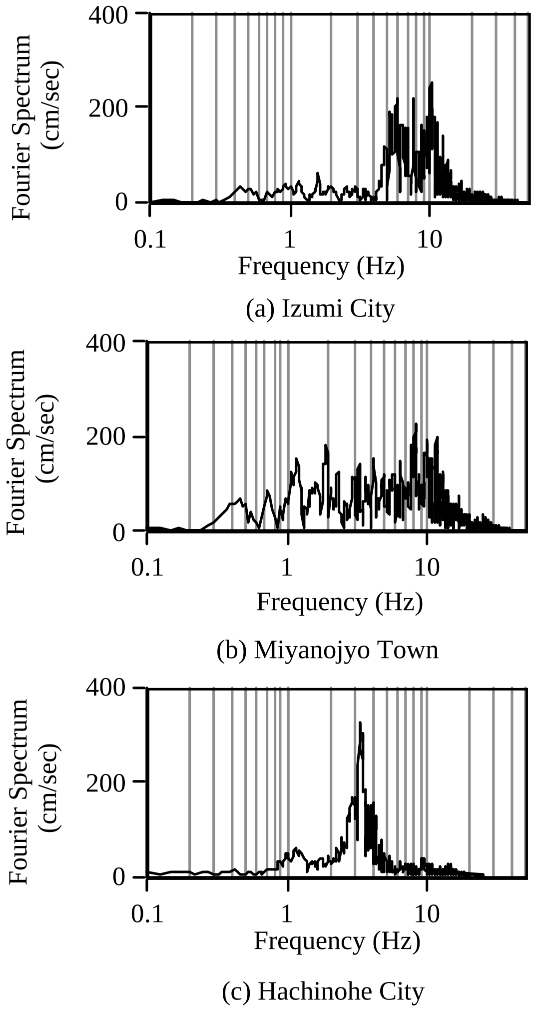

Figure 7: Fourier spectra

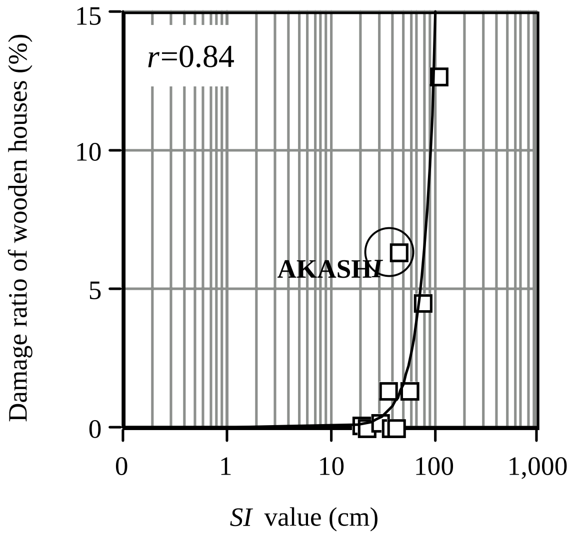

Figure 8: Relationship between SI value and damage ratio of wooden houses

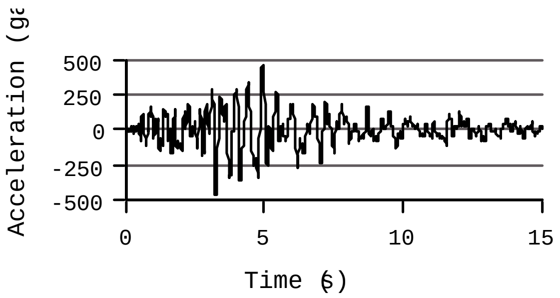

Figure 9: Time history of accelerations (Akashi City)

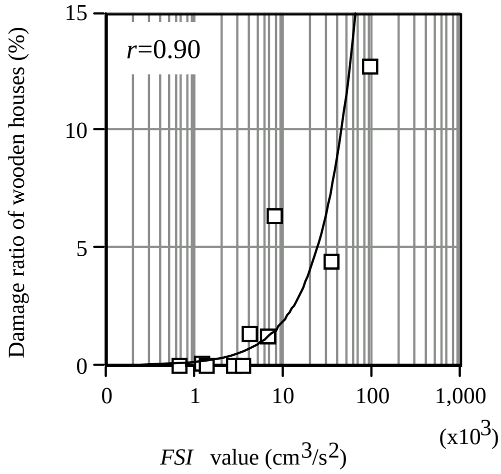

Figure 10: Relationship between FSI value and damage ratio of wooden houses

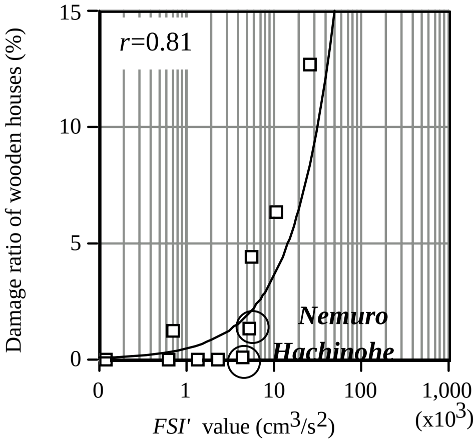

Figure 11: Relationship between FSI' value and damage ratio of wooden houses

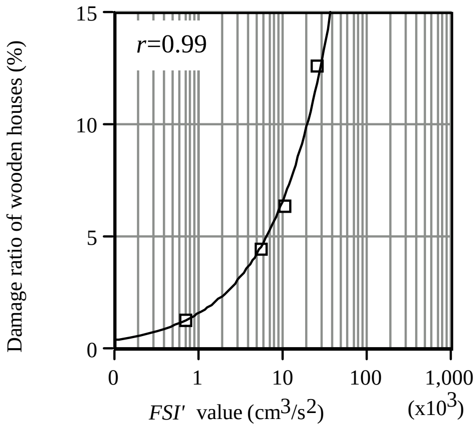

Figure 12: Relationship between FSI' value and damage ratio of wooden houses (for 4 cities in Kobe area)

CONCLUSIONS

The conclusions of this paper are summarised below.

(1) *FSI* and *FSI'* values were proposed in order to consider the effect of fatigue damage. The number of cycles of the large seismic response were considered in these indices.

(2) This *FSI'* value was able to represent the damage more accurately than alternative indices such as maximum acceleration and *SI* value.

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