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STRUCTURAL CHARACTERISTICS OF TRADITIONAL THATCHED HOUSES IN OLD POST TOWNS

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We report the progress of our research on seismic performance estimation of a traditional thatched house in Ouchi-Juku, Fukushima prefecture, registered as an IPDGHB in 1981, based on field surveys. First, we carried out a field survey of two existing thatched houses to understand their structural properties and conducted microtremor measurements of these houses and examined their ground to analyze their vibrational characteristics. Based on vibration mode of the house, it was found that the amplitude was large on the front side, which was used as often as a souvenir shop and Japanese restaurant, because the front of the house had less walls. Finally, we calculated the yield base shear coefficient as an indicator of seismic performance and compared it with the regression functions of traditional town houses in Kyoto. It is found that the thatched house in Ouchi-Juku had a higher shear force than a wooden house in Kyoto.

Keywords: Traditional wooden structure, H/V spectra, Natural frequency, Vibrational mode, Yield base shear coefficient, Ouchi-juku.

1 INTRODUCTION

Many earthquakes have occurred in Japan such as the Hyogoken-Nanbu earthquake in 1995(M7.3) and the Tohoku-Chiho Taiheiyo-Oki earthquake (M9.0) in 2011 damaged many structures (Editorial Committee for the Report on the Hanshin-Awaji Earthquake Disaster 1998, Architectural Institute of Japan 2011). On the other hand, there were traditional wooden structures that did not collapse even after experiencing many earthquakes.

The Ouchi-Juku district on inland Fukushima prefecture, which was registered as an IPDGHB (Important Preservation District for Groups of Historic Buildings) in 1981, is a post town (The Agency for Cultural Affairs 2008, The Agency for Cultural Affairs 2017) and contains many traditional thatched houses. An intensity of a lower five on the Japanese seven-stage seismic scale was recorded near Ouchi-juku; nevertheless, there was no damage to any of the thatched houses. Hence, it is very important to understand the construction and structural characteristics of thatched houses.

The purpose of this study is to analyze the structural and vibration characteristics of a thatched house. First, we carried out a field survey of two existing thatched houses in Ouchi-juku to understand the construction and maintenance methods. Moreover, we conducted microtremor measurements for these houses and analyzed their ground to grasp vibration characteristics.

Finally, we calculated the yield base shear coefficient as an indicator of seismic performance based on the data obtained from the field survey.

2 LOCATION CONDITION OF OUCHI-JUKU IN FUKUSHIMA PREFECTURE

Ouchi-Juku was registered as an IPDGHB in 1981 and is a post town with an inland village. Many households have a thatched house built along the old main road and an extended new house at the back of the thatched house, as shown in Figure 1. The thatched houses are arranged on both sides of the old main road, and the building pitch is large. There are approximately 45 thatched houses in this district. The front of the thatched houses facing the old main road are often souvenir shops or Japanese restaurants because Ouchi-Juku is a tourist spot.

Microtremor measurements of the ground were conducted to clarify the surface ground condition. Figure 2 shows the resultant H/V spectra. The natural frequency is approximately 2.6 Hz in the NS and EW directions.

Figure 1. Thatched houses in Ouchi-Juku.

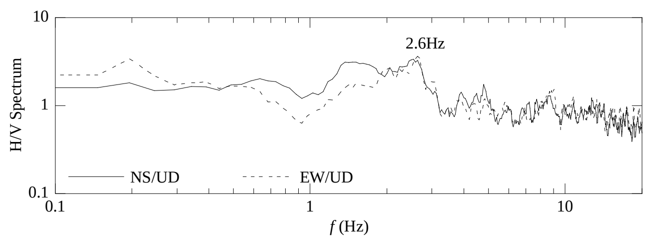


Figure 2. H/V spectra of ground.

3 STRUCTURAL INVESTIGATION OF THATCHED HOUSES

The thatched houses were investigated in Ouchi-Juku from July 28 to 29, 2016. We selected two thatched houses: House A and House B. The following steps were carried out as part of the structural investigation.

- Drawing plans: The floor and sectional plans were drawn to clarify the structural constituents, joint details, house weight, etc.
- Interviews: Inhabitants were asked for house information and maintenance methods.
- Deterioration check: Termite damage, moisture contents of columns, and any inclination of the houses were confirmed.
- Microtremor measurement: Microtremor measurements were conducted for each thatched house.

3.1 Deterioration and Damaged History of Thatched House

House A was built approximately 450 years ago and is the oldest one in Ouchi-Juku. Cedar wood was used for many columns and zelkova was used for the central pillar. The inclinations of the columns were measured, and it was found the maximum deformation angle was 0.04 rad in the ridge and span directions. Moisture contents of the columns were approximately 15 %. Termite damage was not found.

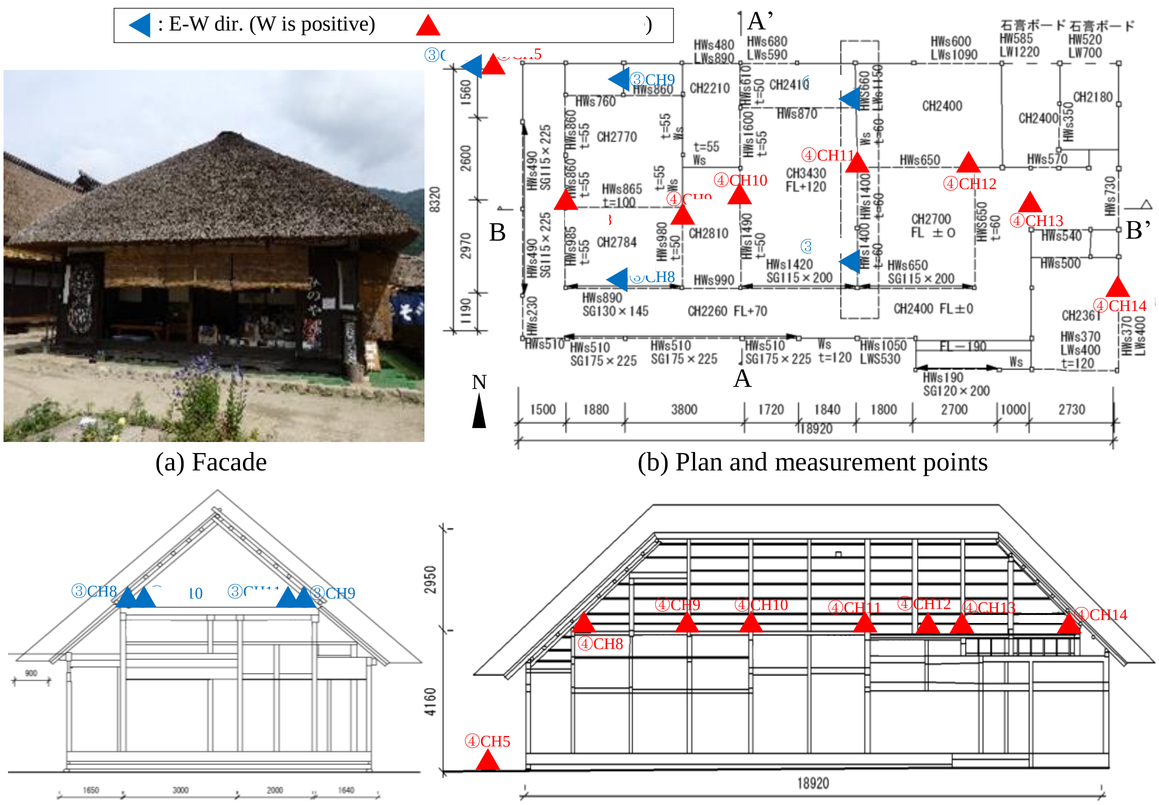
House B was built approximately 200 years ago. Zelkova was used for many columns in the house. The inclination of the columns was determined, and the maximum deformation angle was 0.055 rad in the ridge direction. Moisture contents of the columns were approximately 14 %.

Termite damage was found on the ground sills and columns.

3.2 Drawing Plans and Calculating Weight

As an example, the structure of House A is shown in Figure 3. The appearance of the front facade is shown in Figure 3(a). This was a one-storied house. The plan is shown in Figure 3(b). The cross section along the span is shown in Figure 3(c), and the ridge cross section is shown in Figure 3(d). Columns are set on the ground sill.

Table 1 lists structural parameters of both the houses. The weight of the house was calculated based on the timber volume determined from a drawing (Architectural Institute of Japan 2004). For House A, the number of columns per unit area is 0.37 m^{-2}, and the weight of each column 6.19 kN. For House B, the number of columns per unit area is 0.30 m^{-2}, the weight of each column is 7.41 kN.



(a) Facade

(b) Plan and measurement points

(c) Cross section A-A’

(d) Cross section B-B’

Figure 3. House A.

Table 1. Structural parameters of houses A and B.

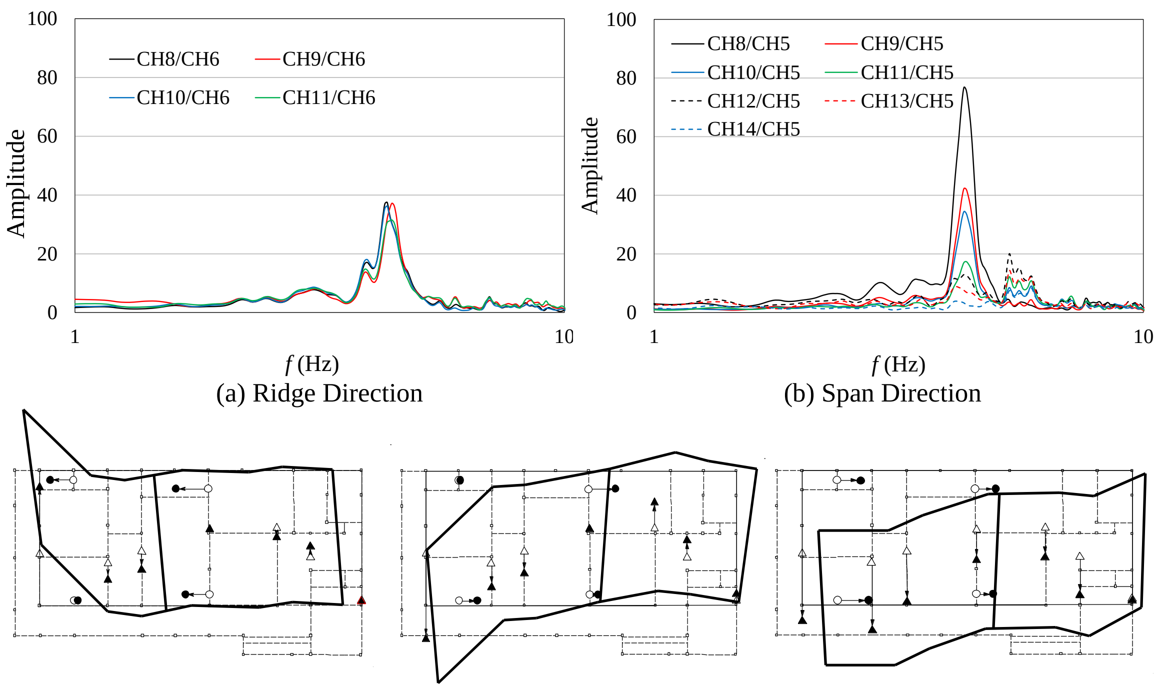
House	Story height (mm)	Weight (kN)	Floor area (m^2)	Number of columns	1st frequency (Hz)		Base shear Coefficient	
					Ridge-Dir.	Span-dir.	Ridge-Dir.	Span-dir.
A	4160	359.3	158	58	4.3	4.2	0.82	0.59
B	4546	630.0	285	85	2.7	3.3	0.38	0.37

3.3 Vibration Characteristics by Microtremor Measurement

Microtremor measurements of both houses were conducted. Several overdamping velocimeters were used, and simultaneous measurements were conducted for 500 seconds.

The result of the microtremor measurements for House A is shown in Figure 4. The measurement points are indicated in Figures 3(b)-(d). Velocimeter CH5 was installed on the ground, whereas velocimeters CH8-CH14 were installed on the attic. The first natural frequencies f_1 are given in Table 1. The first natural frequency f_1 in the ridge direction is 4.3 Hz as shown in the Fourier spectrum ratio in Figure 4(a); that in the span direction is 4.2 Hz as shown in Figure 4(b).

The vibration modes of House A are shown in Figures 4(c)-(e). The west side of the house shows a large amplitude. Because the front of the house is on the west side and is used as a Japanese restaurant, it has few walls.



(a) Ridge Direction (b) Span Direction

(c) 1st mode (d) 2nd mode (e) 3rd mode

Figure 4. Vibration characteristics of House A.

4 ESTIMATION OF YIELD BASE SHEAR COEFFICIENT

The yield base shear coefficient was calculated by simply combining the restoring forces using the limit strength calculation (Japan Structural Consultants Association Kansai Branch 2011, Editorial Committee of Seismic Design Manual for Wooden Framework Structure 2008). In the conventional method, the base shear coefficient at 1/3 rad is used as the yield base shear coefficient C_y. Using the yield base shear coefficient C_y as an indicator, the seismic resistance was evaluated.

The base shear coefficient of House A is shown in Figure 5. The yield base shear coefficient C_y was 0.82 at 1/30 rad in the ridge direction, and 0.59 at 1/30 rad in the span direction.

The relationship between the first natural frequency and yield base shear coefficient is shown in Figure 6. The two curves are regression functions for a traditional wooden town house in Kyoto, Japan, proposed in a previous study (Hayashi *et al.* 2010). The thatched house in Ouchi-Juku has a higher shear force than the wooden house in Kyoto.

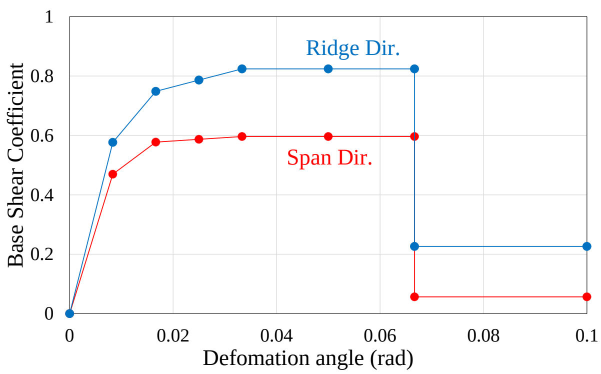


Figure 5. Base shear coefficient of House A.

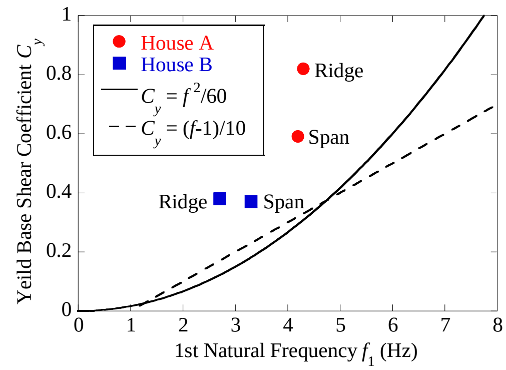


Figure 6. Relationship between f_1 and C_y.

5 CONCLUSIONS

In this study, we estimated the seismic performance of a thatched house in Ouchi-Juku, Fukushima prefecture, through a field survey to understand its structural and vibrational characteristics. First, we carried out field survey of two existing thatched houses to understand their construction and maintenance methods. Moreover, we conducted microtremor measurements for these houses and the ground to analyze the vibrational characteristics. Finally, we calculated the yield base shear coefficient as an indicator of seismic performance and compared it with the regression functions for a traditional town house in Kyoto.

The major findings from this study are summarized as follows:

(i) To clarify the surface ground condition, we conducted microtremor measurements. The natural frequency of the ground is approximately 2.6 Hz.

(ii) Based on the vibration mode of the house, it was found that the amplitude is large on the front side, which is often used as a souvenir shop and Japanese restaurant because the front of the house has few walls.

(iii) The thatched house in Ouchi-Juku has a higher shear force than the wooden house in Kyoto.

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