SHAKING TABLE TEST OF TRADITIONAL TIMBER FRAMES INCULDING *KUMIMONO*

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ABSTRACT: This paper presents the results of the shaking table tests of traditional timber frames with mud wall and without it. The aim of this research is to clarify the vibration characteristics of each element in a frame and the difference of the behavior about *Kumimono,* a structural component between a column and roof, in the two types of specimens. The results of the specimen with mud wall were compared with those of one without mud wall. The vibration characteristics of both whole frame, *Kumimono*and, *Nuki*, a tie beam extending from one pillar to another, is discussed.

Key Words: traditional timber structure, *Kumimono,* shaking table test

INTRODUCTION

The conservation and restoration works of traditional timber structures have been conducted in Japan since the 19th century. Recently, the structural viewpoint is needed in such works. Therefore the quantitative evaluation of their structural behaviors is indispensable. In the buildings such as temples and shrines, column, mud wall, *Nuki* which is a tie beam extending from one pillar to another, and *Kumimono* which is a structural component between a column and roof, etc, are considered as structural elements. Each element has been researched and modeled experimentally and analytically. However it is not clear how each element contributes to the whole structural behavior. In this study, shaking table tests were performed with the two types of specimens. One specimen consisted of columns, *Nuki*, *Kumimono*. Another one included mud wall with another type. The aim of this research is to clarify the vibration characteristics of each element in a frame and the difference of the behavior about *Kumimono* in the two types of specimens.

OUTLINE OF EXPERIMENT

Test specimens

The specimens were the 2/3 scale model of a frame in the *Aska* style of the five-storied timber pagoda as shown in Figure 1. The span between columns was an outside plane of structure in the first story of the pagoda as shown in Fig. 1, in order to clarify the modeling method of the structures consisting of *Nuki*, columns. *Kumimono* modeled the parts of 2 pairs on the central two columns because *Kumimono* in corners is projecting at 45-degree angle in a flat and has complex forms and the aim of this study was to get basic data of each element. A cornerstone was put under each column. They were connected with a dowel. Tree species were yellow cedar.

Two types of specimens were used in the tests as shown in Figure 2. Specimen 1 consisted of

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columns, *Nuki*, *Kumimono*. Specimen 2 was made by adding mud wall between the columns of the Specimen 1.

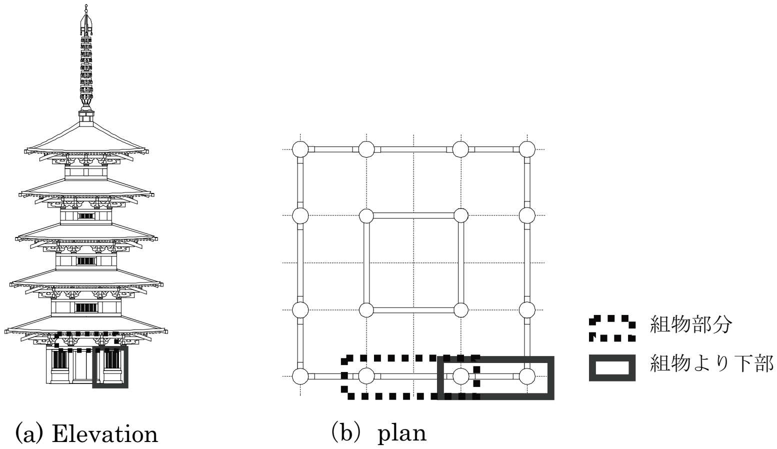

Figure 1. Subject plane of structure

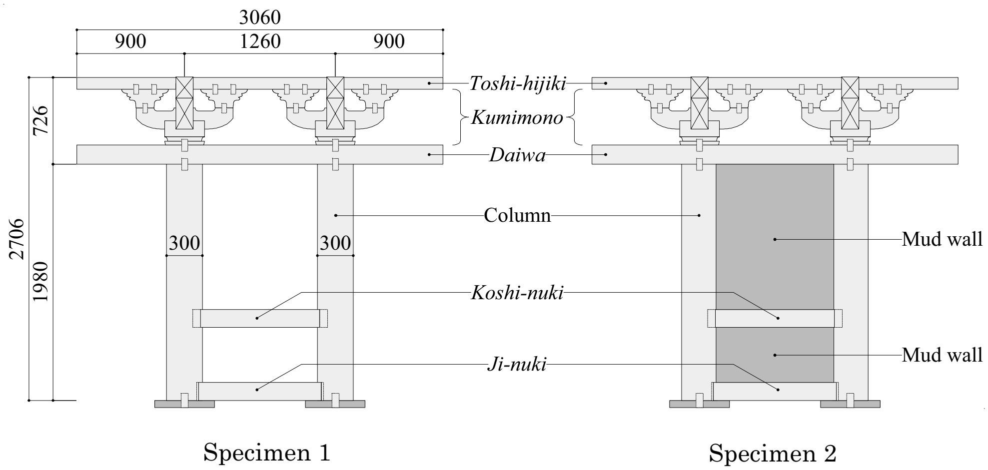

Figure 2. Specimens

Experimental method

The shaking table tests were carried out at the shaking table of Chiba Experiment Station in Institute of Industrial Science. Horizontal unidirectional shaking was conducted. Figure 3 shows the experimental method. The vertical load of 39.9kN made of steel frames and lead was put on the specimen. A load cell to measure axial force and shear force was placed under each column. The acceleration, displacement and the strain of specimens were measured using about 75 devices.

The experiment procedure is shown in Table 1. BCJ-L2, the level 2 of a simulated wave provided from the building center of Japan, was used as a large input motion. In the tests of Specimen 1, the maximum input acceleration was increased by 10% from 10% to 100%. In the tests of Specimen 2, one input with BCJ-L2 20% and two inputs with BCJ-L2 100% were carried out.

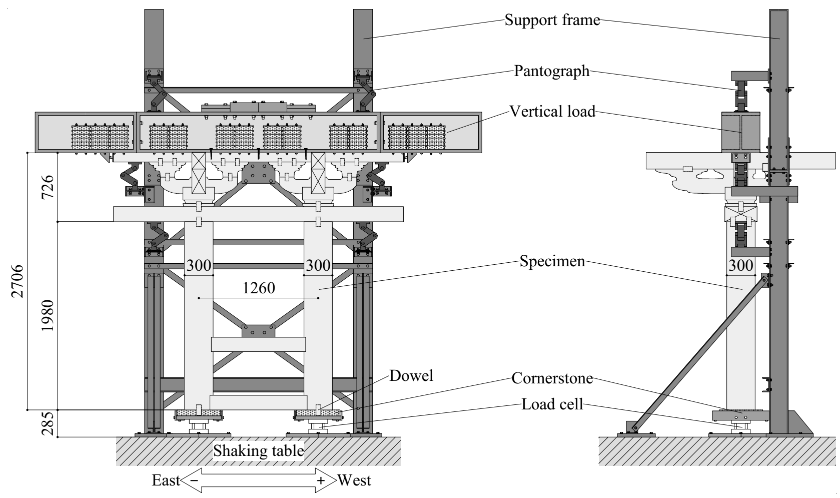

Figure 3. Experimental method

Table 1. Experimental procedure

No.	Specimen (date)	Input Motions	Time	Level
1	1 (2006.5)	Random	30sec	30gal
2		Step	–	1,3,6mm
3		Sine	–	20gal
4		BCJ-L2	120sec	35.6-356gal
5		Random	30sec	30gal
6	2 (2006.12)	Random	30sec	30gal
7		Step	–	1,3,6mm
8		Sine	–	20gal
9		BCJ-L2	120sec	35.6-356gal
10		Random	30sec	30gal

EXPERIMENTAL RESULTS AND DISCUSSIONS

The relationship between load and displacement

Specimen 1

Figure 4 shows the relationship between load and displacement from the inputs of BCJ-L2 20%, 40%, 80%, 100% to Specimen 1. Until the test of 20%, the relationship between load and displacement was linear. After the test of 30%, the relationship became nonlinear. The stiffness went down at the displacement of about 5mm. After the yield point, the hysteresis curve became swollen. The negative gradient appeared in the deformation from the maximum to the origin. The maximum shear force was 10.75kN at the test of BCJ-L2 80%. The maximum displacement was 180.2mm, 1/13rad deformation angle of a column, at the test of BCJ-L2 100%. After the experience of a large deformation, a load around an origin point was increased drastically as shown in the point (a), (b), represented in 100% of Figure 4.

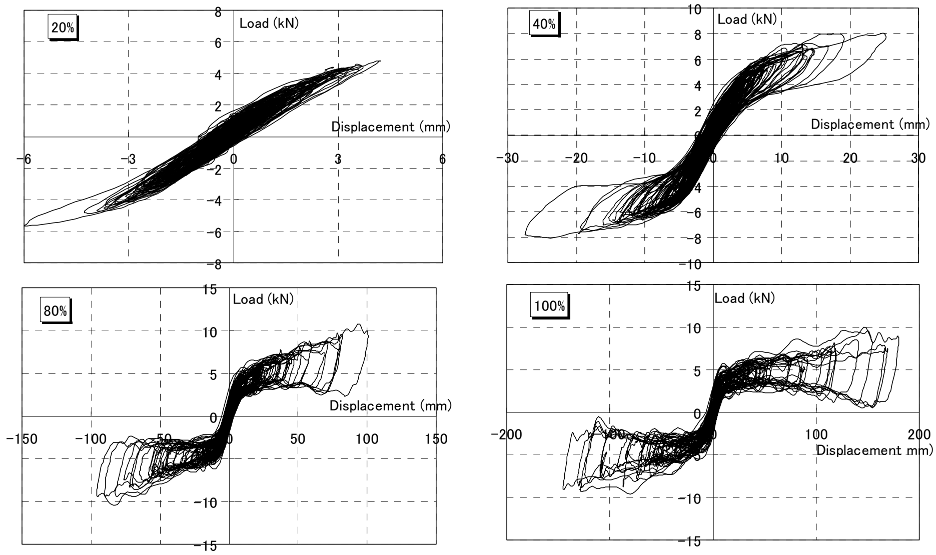

Figure 4. The relationship between load and displacement of Specimen 1

Specimen 2

Figure 5 shows the relationship between load and displacement for the inputs of BCJ-L2 20% and BCJ-L2 100% twice to Specimen 2. In the test of BCJ-L2 20%, the stiffness was higher than that in the test of 20% for Specimen 1. It was assumed to be due to the resistance of the mud wall. In the first BCJ-100%, the load went up to about 12kN within 40mm displacement. It can be assumed to be due to the resistance force of the mud wall. After the collapse of the mud wall, the resistance force of the specimen dropped and a hysteresis curve changed to (2) represented in Figure 5-b. Therefore, in the test of the second BCJ-100%, the load did not rise like the first one. At around 5kN load, the stiffness changed and a load increased gradually up to around 10kN.

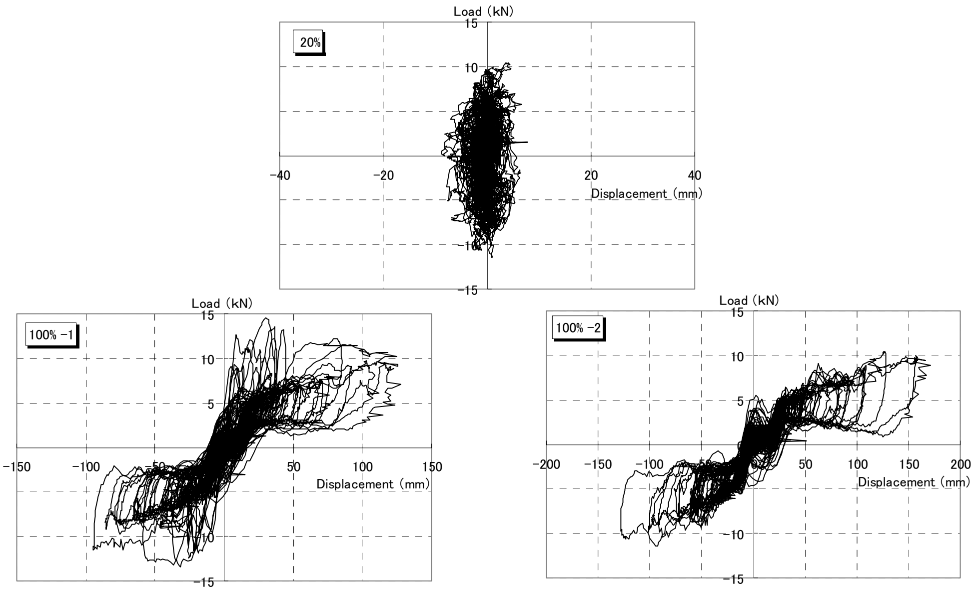

Figure 5. The relationship between load and displacement of Specimen 2

Comparison of Specimen 1 with Specimen 2
Figure 6 shows the relationship between load and displacement for BCJ-L2 100% of Specimen 1 and Specimen 2. The characteristics of every hysteresis curve were almost same after the collapse of the mud wall. However the load of Specimen 2 in the range of (a)-(b) became higher than that of Specimen 1. It can be assumed to be due to the resistance force of mud wall.

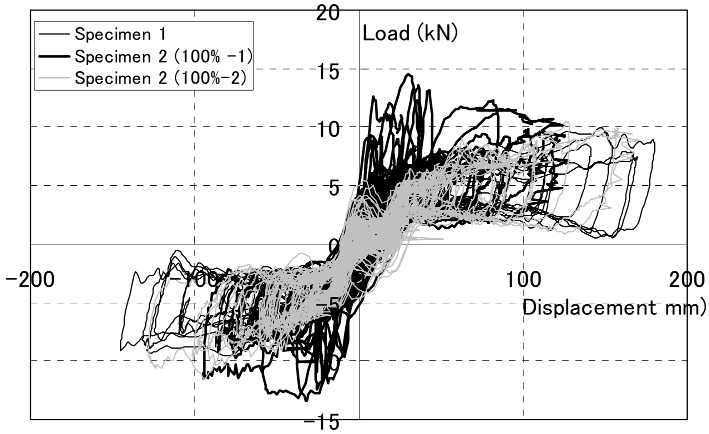

Figure 6. The relationship between load and displacement of Specimen 2

Characteristics of deformation
Figure 7 shows the horizontal deformation of specimens in the range of the maximum amplitude from the test of BCJ L2 100%. Most of the displacement of Specimen 1 was the displacement from the inclination of columns. The line between *Daiwa* and *Toshi hijiki* was vertical almost all time. It means that the displacement of Kumimono was very minute. As for Specimen 2, the characteristic was almost same. However, at the maximum deformation, the line between *Daiwa* and Top inclined. It can be seen that the deformation of Kumimono increased slightly.

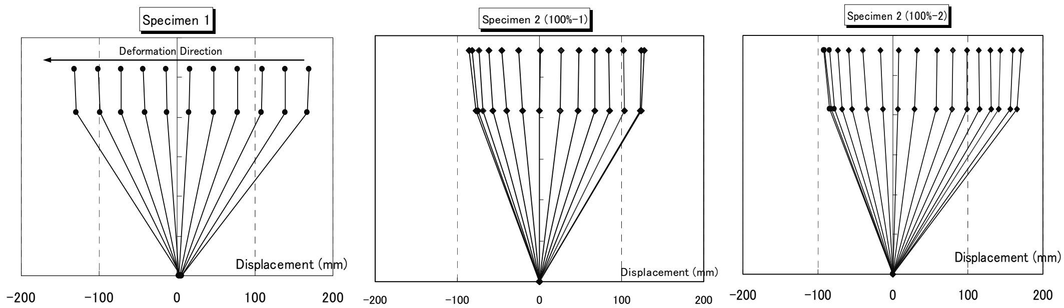

Figure 7. The relationship between load and displacement of Specimen 2

The relationship between load and displacement of Kumimono
Figure 8 shows the relationship between load and displacement of *Kumimono* for all specimens for the tests of BCJ L2 100%. The displacement of *Kumimono* was calculated by subtracting that of *Daiwa* and the displacement happened by the rotation of Daiwa from that of *Toshi hijiki*. The maximum displacement of *Kumimono* in Specimen 1 was about 3mm. The value was very infinitesimal and occupied only about 1% of the displacement of the whole specimen. As for Specimen 2, it was about 8 mm and about 10% of the total displacement of the specimen. The deformation of *Kumimono* in

Specimen 2 behaved fifth as much as that in Specimen 1, but the displacement of *Kumimono* in all specimens was very minute to that of a whole specimen.

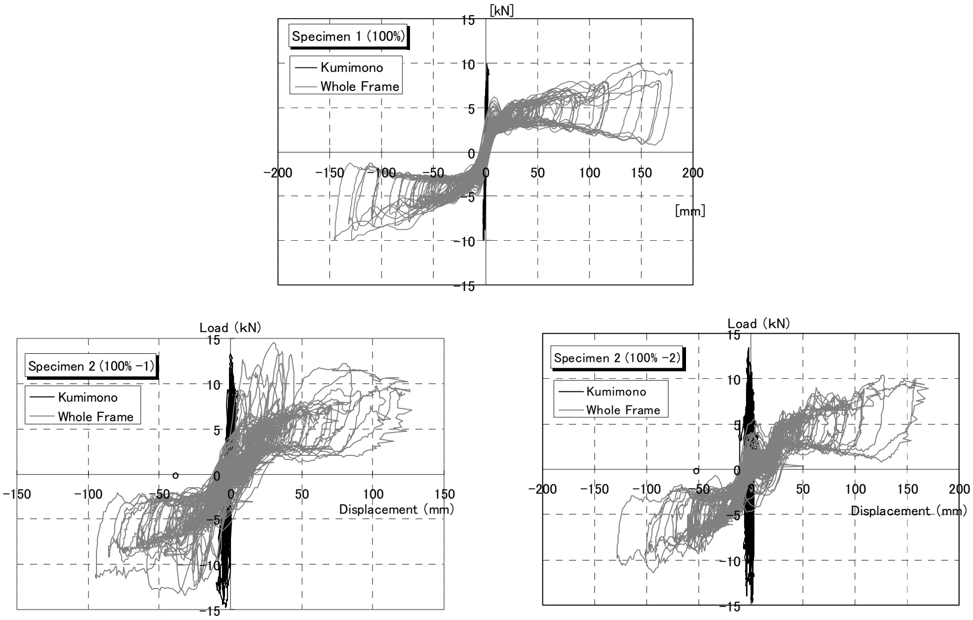

Figure 8. The relationship between load and displacement of *Kumimono* and whole specimens

Bending moment of Koshinuki

When columns inclined, the rotaion motion occurred at the joints of columns and *Koshinuki*. By the motion, the compressive strains inclined to the grain of members came up and bending moment happened at *Koshinuki*. Figure 9 shows the relationship between the bending moment and rotation angle of a joint of columns and *Koshinuki* for Specimen 1 and Specimen 2. The data of each specimen is the sum of all tests because compressive strains inclined to the grain of members did not get back if deformation by crushing stress occurred once. That is called, the resistance of bending moment was 0 kN*mm after one test. The positive rotation angle of Specimen 2 was not same as the negative one. It

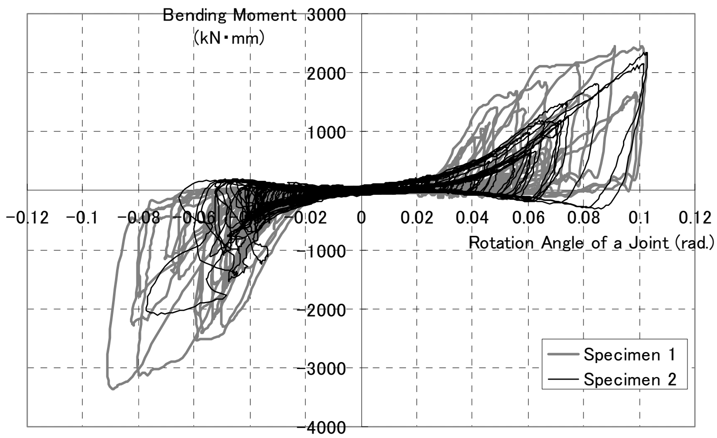

Figure 9. The relationship between bending moment and rotation angle of a joint of columns and *Koshinuki*

can be assumed to be due to the different gap of a column and *Koshinuki* in right and left. The stiffness of Specimen 2 became lower than that of Specimen 1. It can be seen to be due to the reduction of resistance force happened by iteration shaking. However the maximum bending moment was almost same. It was about 2300 kN*mm at 0.1 rad.

CONCLUSIONS

The shaking table tests were carried out using two kinds of plane of traditional timber structure with mud wall and without it. The characteristics of main structure elements in each specimen are discussed.

1) The relationship between load and displacement of Specimen with mud wall (Specimen 2) showed a form in which the characteristic of mud wall was added to the relationship of a specimen without mud wall (Specimen 1). The characteristics of the relationships after collapse of mud wall became almost same. The hysteresis curve of Specimen 2 after collapse followed the almost same route as that of Specimen 1. In the both relationships, the load gradually increased until the maximum displacement. The form of the relationships had swell after about 1/20 rad deformation angle of a column. The deformation of columns was large in that of the whole structure in both specimens.
2) The deformation of *Kumimono* in Specimen 2 became about twice as much as that of Specimen 1. However the deformation was minute comparing with whole structure one.
3) The maximum bending moment and maximum deformation at *Koshihnuki* in Specimen 2 were almost same as Specimen 1. The reduction of the resistance was seen in the relationship between bending moment and rotation angle of Koshinuki in Specimen 2 compared with Specimen 1. It can be assumed to be due to the iteration shaking.
4) The characteristics of each element were discussed with only experimental results but the theoretical evaluations are also necessary.

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