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AN EXPERIMENTAL STUDY ON THE COLLAPSING PROCESS OF WOOD CONVENTIONAL HOUSES -SHAKING TABLE TESTS OF REAL-SIZE MODELS-

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SUMMARY

To reinforce existing wooden houses collapsed by 1995 Hyogo-ken Nanbu Earthquake, it is important to clarify the seismic performance, three-dimensional vibration character, and collapsing process of existing wooden houses. This research, therefore, is intended to clarify the collapsing process of existing wooden houses constructed based on the old code through a full-scale three-dimensional shaking table tests.
In the full-scale shaking table test, the process in which both the first and second stories collapsed simultaneously could be traced. The order of the major damages is shown below:
Falling off and buckling of bracing -> Bending failure of head of column -> Splitting Failure of ground sill -> Collapse.
And from the observation of behaviour of the collapsed house and the not-collapsed house, it is known that some factors would have affected the collapse.

INTRODUCTION

The seismic performance of existing wooden houses differs from that of new wooden houses for the reason of changes in construction technique (specifications) and aging of structural components. Since the building code itself has been revised learn from earthquake damages and experimental studies. Even if house was constructed according to the building code at the time of construction, the house may not always conform to the requirements of the current code. To reinforce these existing wooden houses collapsed by 1995 Hyogo-ken Nanbu Earthquake, it is important to clarify the seismic performance, three-dimensional vibration character, and collapsing process of existing wooden houses.
This research, therefore, is intended to clarify the collapsing process of existing wooden houses constructed based on the old code through a full-scale three-dimensional shaking table tests.

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OUTLINE OF EXPERIMENT

Experiments

Test houses were used to examine the effects of combination of three-dimensional input motions. To investigate the fundamental performance of wooden houses constructed 30 or 40 years ago, four test houses were designed according to the code before amendment of earthquake resistance standard in 1980. Input motions of one dimension (direction X or Y), two dimensions (X and Y) and three dimensions (X,Y and Z) were given to the test houses by a shaking table.

Test Houses

Test houses are two-storied and their dimensions are 3640mm X 5450mm in plan as shown in Fig. 1. The houses conform to the specifications provided before the amendment of seismic design code in 1980 and are based on the common specifications by the Housing Loan Corporation in 1979.
The required wall amount in a wooden house against seismic force has changed with the amendment of seismic design code. Then the required wall amount 30 to 40 years ago is smaller than that of in the current code by 27%.
(1) Specifications of each part: The specifications of wood and metallic material were determined as shown in Table 1 based on the common specifications by the Housing Loan Corporation in 1979. Although the specifications of the Housing Loan Corporation include specifications of metallic material at joints, poor metal joints were used in houses constructed 30 to 40 years ago. The test houses, therefore, are classified as high quality in those days.
(2) Weight of test houses: The weight of test houses including additional weights representing weight of finishings and live load are 22.4(kN) at the roof and 53.1(kN) at the second floor.
(3) Wall amount: The wall amount against seismic force was basically determined as follows.
X direction: The minimum wall amount required in the code amended in 1960 was used.
Y direction: In a wooden house, larger openings exist in one direction and more wall amount exists in its orthogonal direction in many cases. In the Y direction, therefore, the minimum wall amount required by the current code was placed.
(4) Natural frequency: To investigate the difference of the performance of test houses, the micro tremor was measured before the tests to obtain the natural frequency and free vibration tests were carried out to obtain the damping ratio. The results are shown in Table 2. Although four test houses had same shape and same specification, the performance of test houses were different. Although the difference among test house No. 1 to No. 3 are small, for test house No. 4, the natural frequency is low and the damping ratio is high compared with the other houses.

Input Motion

To investigate the difference of behaviours among test houses, the JR Takatori station record from the 1995 Hyogo-ken Nanbu Earthquake were applied. The maximum accelerations of input motion were 741gal in X-direction, 624gal in Y-direction and 279gal in Z-direction.
Table 3 shows the combination of input motions for test houses.

Measurement System

To trace collapse of wooden houses, it is required to measure positive and negative horizontal displacement as large as the height of test houses. It is difficult to measure such large displacement with a conventional winding type displacement gauge. In this experiment, an image measuring method with video camera was used to measure the displacement. The method worked very well up to the displacement of ±2500 mm.

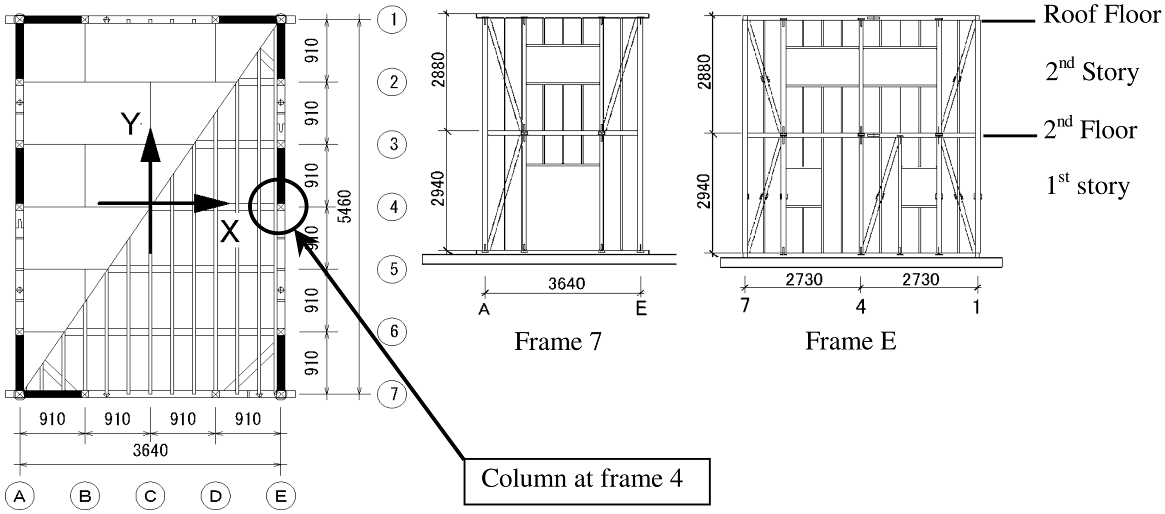


Fig.1 Test House

Table. 1 Specification of Test Houses

Element	Dimension (mm)	Wood
Column	120×120	Japanese Cypress
Column	105×105	Japanese Cedar
Beam	105×300	Western Hemlock
Cross Beam	105×105	Western Hemlock
Bracing	27×105	Japanese Hemlock
Floor	13	Japanese Cedar

Anchor Bolt	M12@2700
End of Bracing	5 x FN65 nail
End of Column	T-shaped Plate
End of Beam	Dabo Joint with Bolts

Table.2 Natural Frequency of Test Houses

		No.1	No.2	No.3	No.4
Natural Frequency (Hz)	X	2.02	1.93	1.98	1.76
	Y	2.37	2.28	2.49	2.25
Dumping Ratio	X	0.026	0.024	0.027	0.031
	Y	0.021	0.022	0.018	0.035

Table.3 Input Motion

Test House	JR Takatori record			
	X	Y	Z	
No.1	741gal			R-1Dimension
No.2		624gal		T-1Dimension
No.3	741gal	624gal		RT-2Dimension
No.4	741gal	624gal	279gal	RTU-3Dimension

EXPERIMENT RESULT

Occurrence of Collapse

When input motions of JR Takatori records were applied to the houses, No. 1 and No. 3 collapsed at both the first and the second story simultaneously [Photo 1]. In the meanwhile, the house No. 4 to which three-dimensional motions (X, Y and Z) were applied did not collapse, though large residual displacement of 356.5 mm (1/7.4 rad.) at the first story and 314.9 mm (1/9.1 rad.) at the second story were measured (Photo 2).

Collapse Process

Fig. 2 (2) shows the collapse start time and collapse complete time of each test with black circle (●). The collapse start time is defined as the time at which the deformation starts to go one direction regardless of movement of the shaking table. The collapse complete time is defined as the time at which the roof came in contact with the ground. For both No. 1 and No. 3, it took approximately two seconds from the start of collapse to the completion of collapse, and slowly collapsing process of wooden houses was observed.

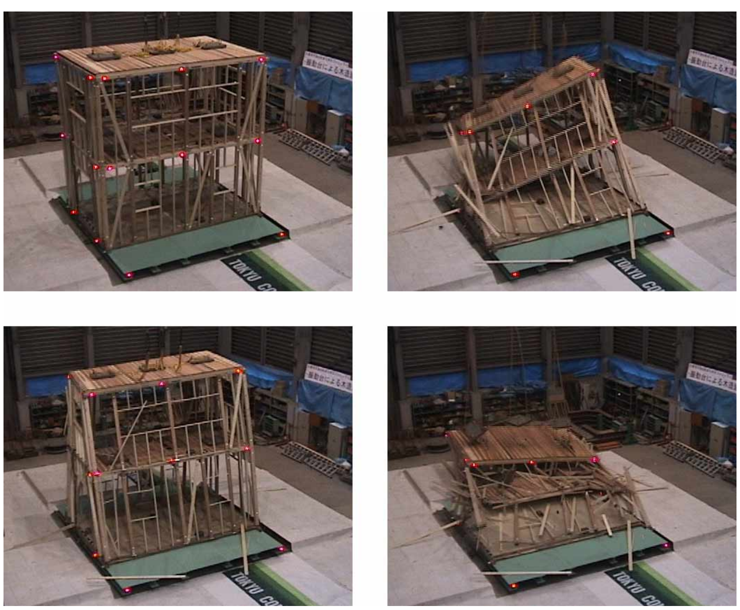
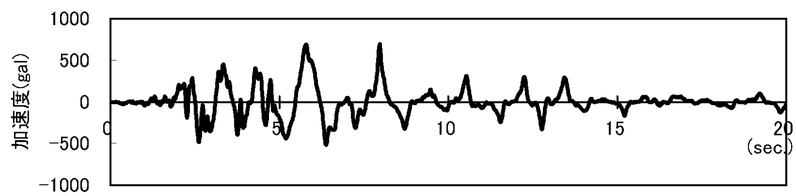


Photo.1 Collapse Process (No.3)

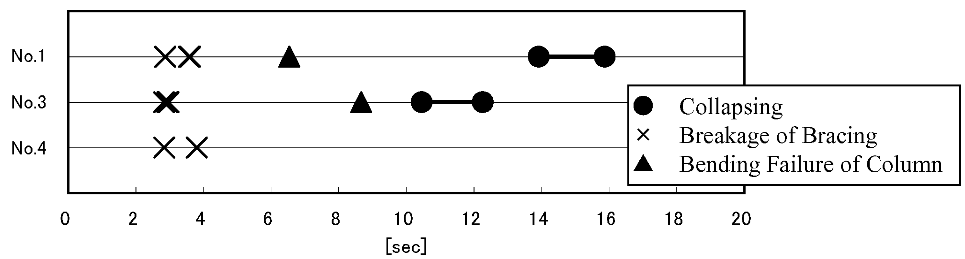
Photo.2 Residual Displacement(No.4)

(1)Breaking of Bracing (2)Bending Failure of Column (3)Splitting Failure of Ground Sill

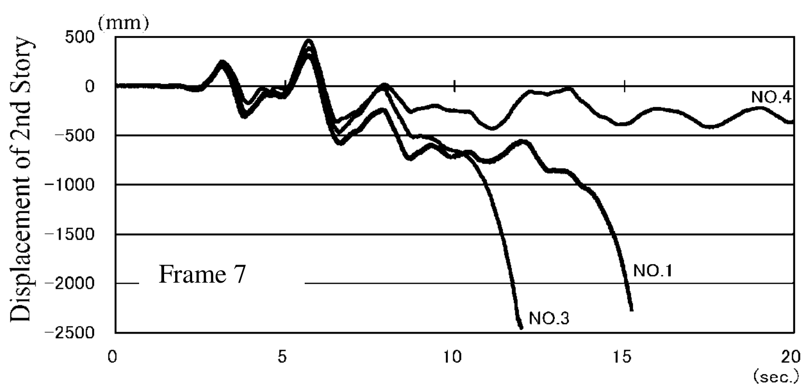
Photo.3 Detail of Damages



(1) Acceleration of Shaking Table



(2)Damage of Houses



(3) Relative Story Displacement (Frame 7)

Fig.2 Damage of Test Houses

These houses were damaged and collapsed in the order of (1) falling off bracings [Photo.3(1)], (2) buckling of them, (3) bending failure of upper portion of columns [Photo.3(2)] and (4) splitting failure of ground sills [Photo.3(3)].

Breakage of Bracing

The mark X in Fig. 2 (2) shows the time at which buckling and falling off occurred on three bracings (at the first story) located in the X direction. Eventually, all bracings of test houses lost its function because of falling or buckling. The figure shows that damages of all the bracings at the first story occurred near the first peak displacement (2.7 to 4.0 sec.) of input motion.

The collapse started at 10sec. or later, and all bracings lost its function at the time of the maximum (positive and negative) acceleration of input motion. It is considered that the resistance after the breakage of bracings was provided by the moment resisting fame effect of intermediate frame on the frame 4 in Fig.1.

Bending Failure of Column Head

The mark, black triangle (▲), in Fig. 2 (2) shows the time at which the bending failure of intermediate column occurred at the upper portion, i.e., at the level of the bottom of the beam. It is considered that the bending failure of column head occurred near the time when the relative story displacement at the first story shown in Fig.2(3) exceeded 500mm (1/5.9 rad.). The through columns at the four corners did not break until collapse occurred.

Splitting Failure of Ground Sill

When collapse occurred, the ground sill was splitted at the row of nails of T-shaped plate.

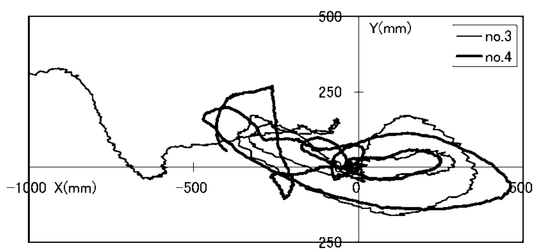


Fig.3 Trace of the 2nd Floor

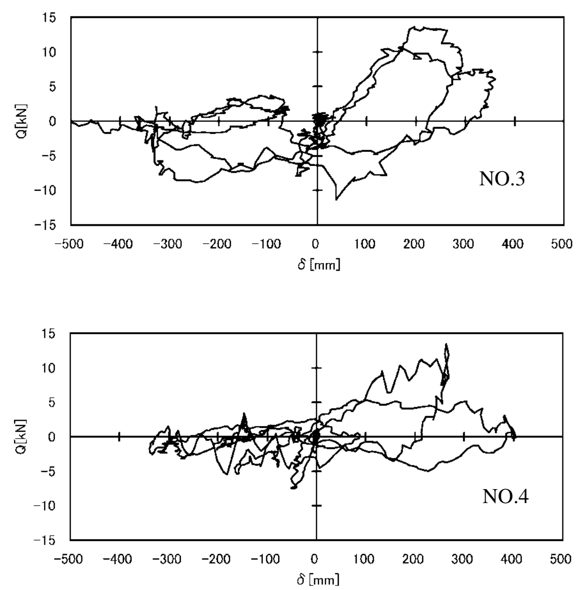


Fig.4 the relationship between the load and deformation

DIFFERENCE BETWEEN COLLAPSED HOUSE AND NOT-COLLAPSED HOUSE

Fig. 2(3) shows the time histories of the relative story displacement in the X direction at the first story of collapsed houses (No.1 and No.3) and a not-collapsed house (No.4). Both houses show similar displacement history on the frame 1 and frame 7 until approximately six seconds. But they show different behavior on the frame 7 after the peak of 6.7 seconds. Although the displacement returned after that, the house No.3 did not return completely to the positive direction before the next peak. The deformation just before this is 500 mm (1/5.8 rad.).

The trace of the second floor is shown in Fig.3. The trace of the test house No.4 differs from that of the test house No.3 and the maximum displacement on the positive side is larger in No.4 than in No.3. Concerning the deformation on the negative side, the deformation in the Y direction toward the positive side is larger in No.4 than in No.3.

Fig.4 shows the relationship between the load and deformation on the frame 7. The relationship between the load and deformation on the positive side at the second loop shows much more degradation of rigidity in No.4 than in No.3. As shown in Table 3, the natural frequency of the test house No.4 is lower than that of the test house No.3. It means that both the initial rigidity and decreased rigidity were lower in the house No.4 compared with the house No.3.

CONCLUSIONS

In the full-scale shaking table test, the process in which both the first and second stories collapsed simultaneously could be traced. The order of the major damages is shown below:

Falling off and buckling of bracing -> Bending failure of head of column -> Splitting Failure of ground sill -> Collapse.

From the observation of behavior of the collapsed house (No.3) and the not-collapsed house (No.4), it is known that the following factors would have affected the collapse,

(i) Combination of input motion (XY, XYZ)
(ii) Difference of initial properties of houses (initial rigidity)
(iii) Maximum displacement at the second loop (decrease of rigidity)
(iv) Whether the bracing is falling off or not
(v) Whether bending failure of column occurs or not.

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