Development of Teaching Materials to Demonstrate Collapse of Wooden Houses for Promotion of Seismic Retrofitting

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The authors have developed a series of teaching materials called BURURU for vibration testing. The materials are used for teaching dynamics in universities and enlightening the public about disaster prevention. Here, a 1/10 scale model of a wooden house is placed on a hand cart, which is a kind of shaking table, in order to demonstrate the seismic weakness of a wooden house for the promotion of seismic retrofitting. By varying the numbers of seismic resistant members, the joints, the weight of the roof, the soil stiffness, and the balance of members, etc., this model allows different collapse mechanisms to be shown easily.

Keywords: Wooden house, Collapse, Teaching materials, Promotion of seismic retrofitting, Video

1. Introduction

Since the Southern Hyogo Prefecture Earthquake, there have been calls to reinforce existing wooden houses that do not satisfy specified earthquake resistance, and many local governments have provided financial assistance for seismic diagnosis and reinforcement. In recent years, people have been prompted to make preparations for earthquakes forecasted to hit in the near future, for example in the Tokai, Tonankai, Nankai, off-Miyagi, and Metropolitan areas. These earthquakes may cause very serious disasters, so at the end of fiscal 2004, the Central Disaster Prevention Council planned seismic disaster prevention strategies for an earthquake occurring in the Tokai, Tonankai, or Nankai districts with the aim of reducing damage in disasters by half within ten years.

Reinforcing wooden houses is the most urgent and important problem in Japan. However, progress is not good. There are many factors blocking the progress of reinforcement, one of which is a lack of easy-to-understand information for residents regarding the need to reinforce houses. Accordingly, we have developed materials for disaster prevention education to increase residents' awareness of disaster prevention and house reinforcement[1-2]. The experimental teaching material "BURURU[3]" has a particularly significant educational effect because it is able to demonstrate the response and vibration of a building subject to an earthquake, which varies depending on the number and balance of shear walls and the roof's weight. Through our participation in a variety of lectures, elementary school classes, and housing fairs, we have found that BURURU is helpful in triggering seismic diagnosis and reinforcement.

Being an all-in-one suitcase in which a shaking table and models are all packed, the first BURURU employed a universal joint to change rotational motion generated by turning a handle by hand to translational motion (see Photo 1). After that, we developed a lighter and

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electrically driven BURURU (see Photo 2). As of now, more than 100 BURURUs are used for antiseismic or disaster prevention education all over Japan. However, Hand-rotated and Electric BURURUs have the following disadvantages: They are ineffective when used in the gymnasium of an elementary school because of their small size, and the participants do not feel that the building models are realistic because they are too simple and small and demonstrate only shaking, not collapse.

Photo 1: Hand-rotated BURURU

Photo 2: Electric BURURU

Accordingly, we decided to develop a teaching material able to shake a large model to concretely demonstrate how to reinforce it to many people while letting them feel the model was realistic and showing the seismic weak points of the model house. We made a shaking table from a commercial cart and a 1/10 scale model of a wooden house. Firstly, we developed the shaking cart and used a nondestructive single-story building model (called Hand Cart BURURU). Secondly, we used the first shaking table and developed a 2-story house model that was more precise as well as destructive (called Wooden House Collapse BURURU). The second BURURU allows two models—one reinforced and the other not—to be loaded together on the cart to demonstrate the difference between how they collapse.

Moreover, we made a promotional video titled “Model Experiments Showing Key Points for Reinforcing Wooden Houses” that shows various experiments with Wooden House Collapse BURURU and a PowerPoint file that describes the experiments. We present a video clip on our website. These materials can be used with the reinforcement promotion video “Is Your House Safe?—Recommending the Seismic Diagnosis and Reinforcement of Wooden Houses” to increase the educational effect.

In this paper, we describe the teaching materials mentioned above.

2. Hand Cart BURURU

We made the shaking table of Hand Cart BURURU by adapting a commercial cart. As shown in Figure 1, we installed a driving shaft with play at the end of the cart and put it on a block. Moving the handle to and fro gives horizontal reciprocating motion to the cart. Apart from the large wooden building model, schoolchildren can also stand on the cart, which allows them to directly feel the vibration.

The left illustration of Figure 2 shows an approximately 1/10 scale model of a building. This simple single-story wooden house model consists of columns, beams, and a roof. Braces can be attached to or detached from the four sides of the building with Velcro fasteners.

Since the stiffness of the columns is high in relation to the building's weight, we use a loose joint between the columns and beams as shown in the right illustration of Figure 2 to let them deform at the joint easily. The model is presented as a kit so that children can enjoy making it while learning the role of each component.

When conducting an experiment with Hand Cart BURURU, we use Hand-rotated and Electric BURURUs together to show the effect of the roof's weight and the availability and arrangement (imbalance) of braces on the resulting vibration. We also place miniature pieces of toy furniture in the model to demonstrate that they fall down.

This teaching material is particularly effective in disaster prevention education at elementary schools. We have already used it at more than 30 elementary schools for "Joint Parent and Child Seismic Disaster Prevention Education" [(5)] held by the Aichi Prefecture Board of Education from FY2003 to FY2004. Moreover, many disaster prevention leaders and volunteers ask us to lend them Hand Cart BURURU.

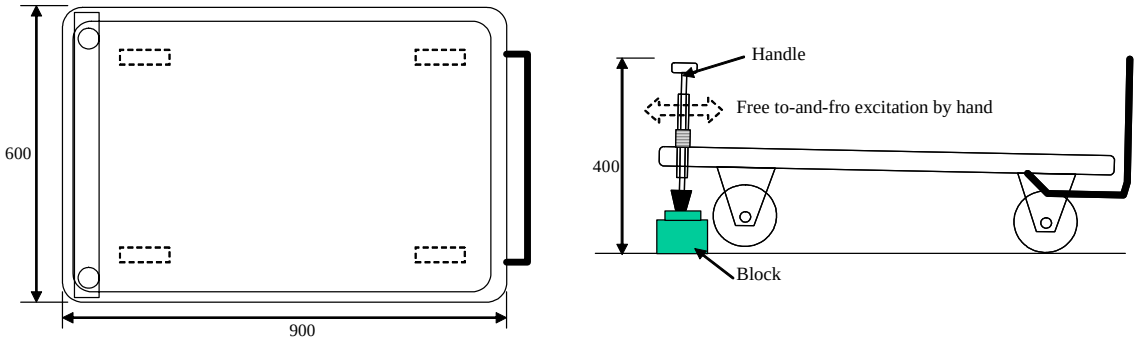

Figure 1 Plan (left) and elevation (right) views of the shaking cart

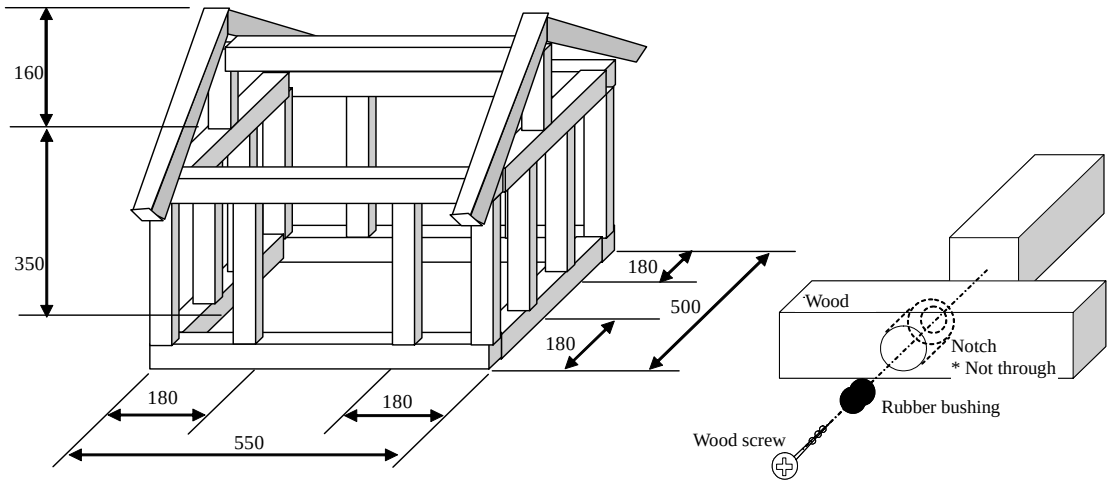

Figure 2 Appearance and dimensions of the single-story building model of Hand Cart BURURU (left) and enlarged view of a joint

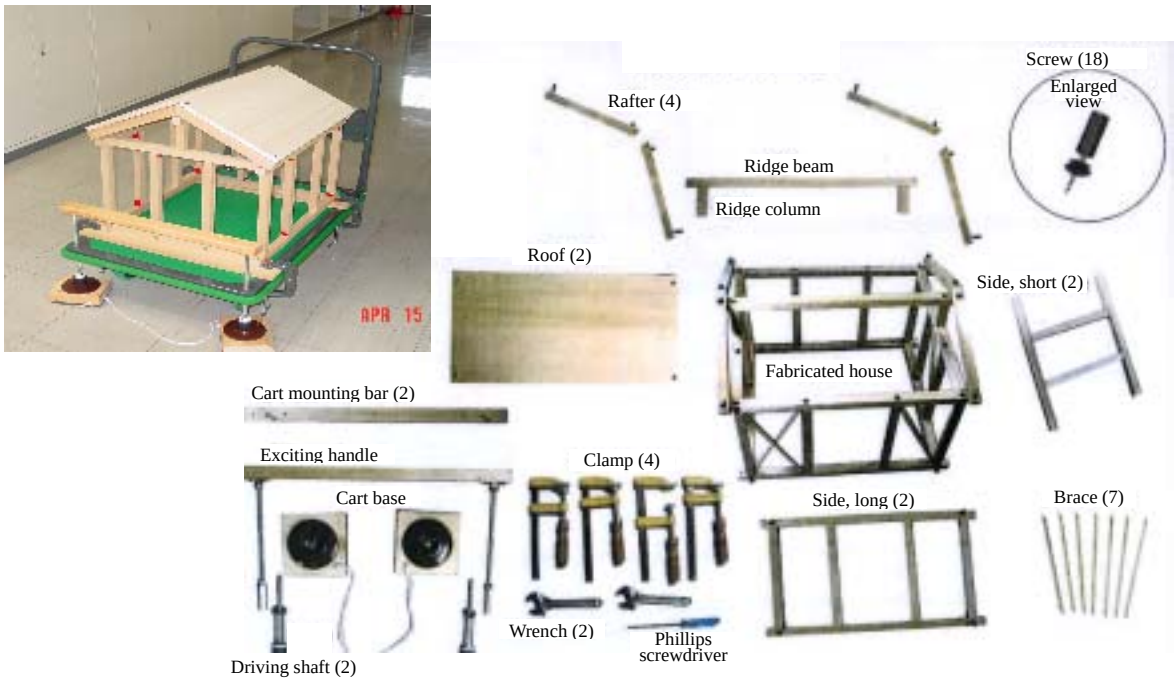

Figure 3: Model kit and photo of the fabricated house

3. Wooden House Collapse BURURU

Use of Hand Cart BURURU proved that the shaking cart was effective in shaking tests, but some users said that the promotion of reinforcing wooden structures needed a teaching material concretely showing the effect of individual reinforcement methods. Accordingly, we developed Wooden House Collapse BURURU based on Hand Cart BURURU. The purposes of this new BURURU are (1) to reproduce the collapse of a typical wooden house caused by an earthquake as precisely as possible, (2) to easily compare vibrations and collapsing states caused by various structural problems, and (3) to demonstrate several patterns at once using easily carried equipment.

(1) Outline of the model

Assuming a conventional 2-story framed building about 3.6 m wide and 5.4 m long, we make two 1/10 scale models of wooden houses. A lecturer gives a demonstration while shaking the cart on which the two models having different structures are loaded together. Considering past wooden house disasters and the test results from a collapsed full-scale wooden building[4], we designed the model so that the joints break first—each member and joint can be soft or rigid. Figure 4 shows the outline of the model. The law of similarity estimates that the natural period T' of the model is shorter than T of the real building ($T' = T\sqrt{10}$), which makes it difficult to demonstrate real vibration. Therefore, we adjust the joint stiffness to bring the former close to the latter ($T \approx T'$). We have also created ways to put each joint together easily.

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Table 1 shows the basic specifications of the model that employs Japanese cypress members for columns, beams, braces, studs, and lintels as well as ash members for the base. To simulate the breakdown of columns, we make 4 balloon framing columns at the corners and laths of balsa. A plastic tenon is attached to each column and Velcro fasteners substitute for metal brackets to join the columns and beams. To simulate a solid floor, we employ plywood and add a lead weight as a live load. For the roof, we prepare two plates with different weights: paulownia and styrene paper sheets. Assuming soft ground, we use a urethane resin base usually used in nursing for avoiding bedsores. As an example of vibration control, we install dampers in each joint.

In addition to the house model, we prepare furniture with built-in weights and removable brackets to prevent overturning as well as concrete-block fences with removable reinforcing bars and buttresses.

Table 1: Specifications for Wooden House Collapse BURURU

Balloon framing column: Balsa	Beam: Japanese cypress
Story column: Japanese cypress	Base: ash
Column tenon: Plastic bar (soft polystyrene)	3-division brace: Japanese cypress Brace end: Goggle tenon on beam
Stud and lintel: Japanese cypress	Joint: Velcro fastener
Floor: 5.5 mm MFD	Heavy roof: 6 mm paulownia plate
Rigid ground: 15 mm MDF	Light roof: 6 mm styrene paper
Soft ground: Urethane	
Structural plywood: 3 mm thick and fixed at end	Damper at joint: Hardware and double-sided adhesive tape for rough surface
Lath: 1 mm balsa	
Shaking table: Cart and exciting bar	Model weight: 9.1 kgf (including two 1 kg weights)

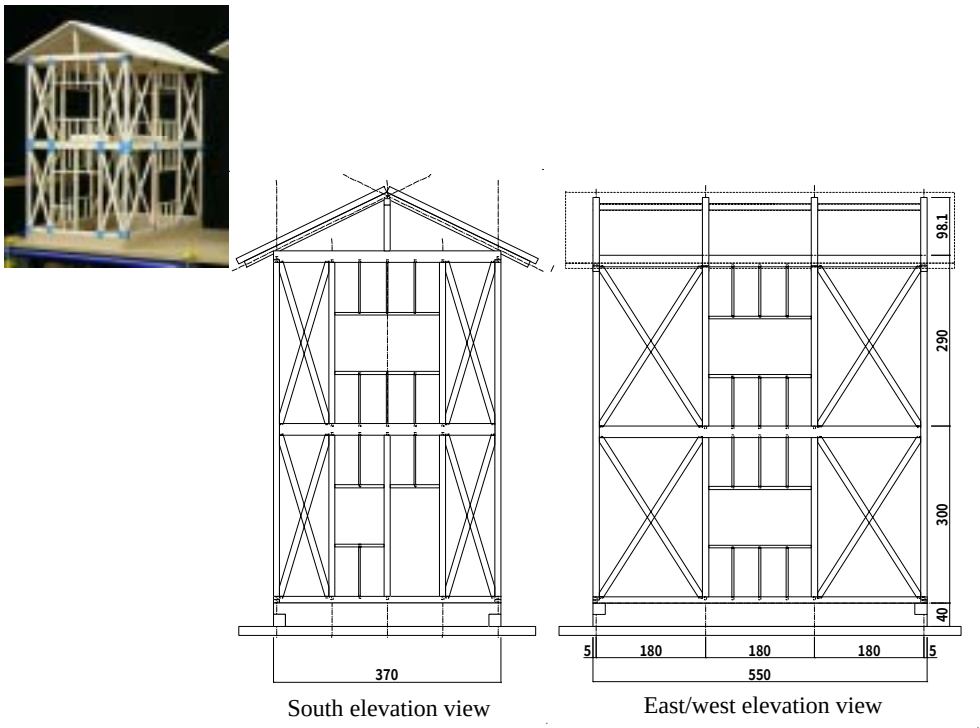


Figure 4: Appearance and dimensions of the 2-story building model of Wooden House Collapse BURURU

(2) Structural characteristics of the model

We reinforced the model by putting four sets of braces crossing each other on the front side of the first and second stories and conducted static loading and shaking tests to check the fundamental structural characteristics of the model. In the static loading test, we pulled the spandrel wall of the second story horizontally with a spring balance, and in the shaking test, we installed seismographs on the ground and second floor and vibrated the table horizontally. Figure 5 shows the resulting hysteresis characteristics and Table 2 lists the resulting natural periods of the model. The results show that the model is relatively similar to a wooden house without exterior and interior components.

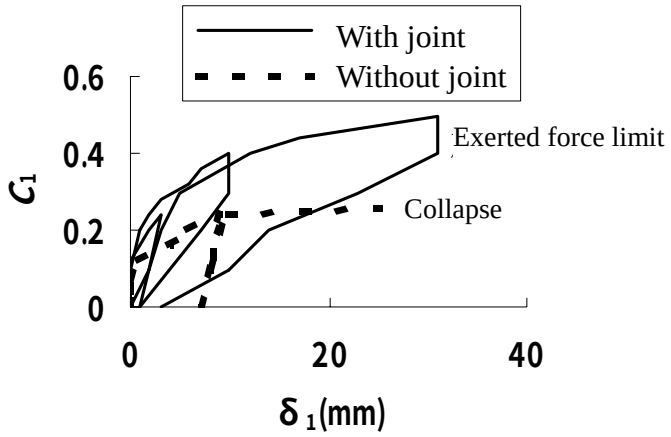


Figure 5: Hysteresis curves of the first story

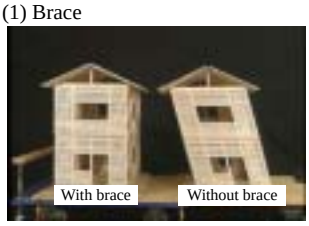
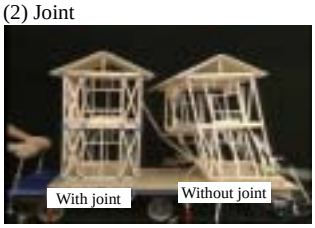
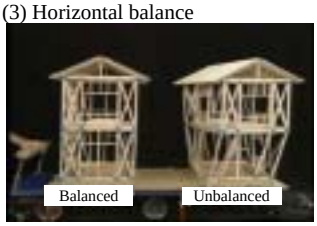
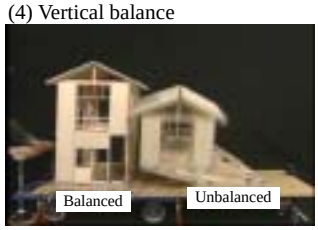
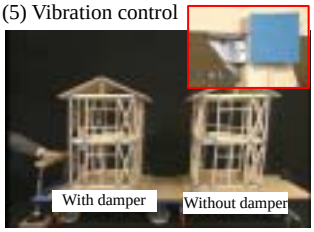
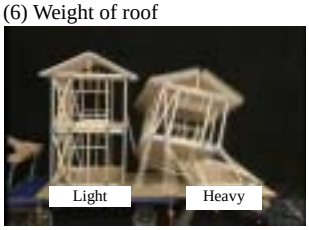
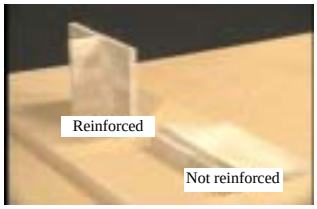
Table 2: Natural periods of the model

Excitation level	With joint	Without joint
Low	0.21 seconds	0.11 seconds
High	0.56 seconds	0.61 seconds

(3) Main experimental patterns

Table 3 lists the main experimental patterns used with Wooden House Collapse BURURU. The patterns are (1) the availability of braces, (2) the availability of joints, (3) horizontal balance, (4) vertical balance, (5) the presence of vibration controllers, (6) the roof's weight, (7) the quality of the foundation, (8) the quality of the ground, (9) the availability of furniture reinforcement, and (10) the availability of concrete block fence reinforcement. Under these conditions, Wooden House Collapse BURURU can be used to compare the difference between the collapse of the right and left building models.

Table 3: Main experimental patterns with Wooden House Collapse BURURU

Pattern	Description	Pattern	Description
(1) Brace 	Building A: With brace Building B: Without brace B tilts when small quake occurs. Outer lathed and off-mortar wall has little resistance to quakes.	(2) Joint 	Building A: With joint Building B: Without join B collapses totally because brace pushes and removes column and joint breaks
(3) Horizontal balance 	Building A: Balanced Building B: Unbalanced on 1st floor B shakes greatly though it has joints, and the 1st floor having large opening collapses while balloon framing column is twisted and broken.	(4) Vertical balance 	Building A: With plywood on 1st and 2nd floors Building B: With plywood on only 2nd floor First floor of B is damaged because stiffness is unbalanced. A is balanced because it has plywood in upper and lower parts of opening.
(5) Vibration control 	Building A: Damper at joint Building B: No damper at joint A shakes a little but shaking calms down soon because 6 joint dampers installed in column heads of each floor absorb energy.	(6) Weight of roof 	Building A: Light roof Building B: Heavy roof A is little damaged regardless of few braces because it has a light roof which decreases inertia force.
(7) Foundation 	Building A: Fixed foundation Building B: Free foundation B rocks because anchor bolts do not work, and collapses because foundation breaks at corner.	(8) Ground 	Building A: Rigid ground Building B: Soft ground Upper frame of B is damaged because soft ground amplifies effect of quake. Interaction with ground (rocking) occurs.
(9) Furniture 	Building A: Fixed with bracket Building B: Free Furniture in B falls down as soon as quake occurs, and floor camera shows that there is no time to escape.	(10) Concrete block fence 	Wall A: With reinforcing bars and buttresses Wall B: Without reinforcing bars and buttresses B falls down from its roots because inertia force increases bending moment.

Wooden House Collapse BURURU has an extremely high educational effect because experiments with it can clearly demonstrate shaking and collapsing differences on the basis of the reinforcing pattern, and because it generates breaking noise, which adds realism. It can also show that response varies depending on the exciting amplitude or period. As a supplemental material, we have made a teaching video titled "Model Experiments Showing Key Points for Reinforcing Wooden Houses" by arranging the videos shown in Table 3 and adding narration. Close-ups and slow-motion replays of the video can increase the educational effect.

Moreover, we have created a PowerPoint file to show how to use Wooden House Collapse BURURU and have copied the video and file onto a DVD, which can be used by disaster prevention leaders and wooden house surveyors. Our website presents motion pictures for e-learning so that visitors can learn about seismic properties[5].

Wooden House Collapse BURURU can be effectively used in university lectures and practical lessons because installing seismographs and displacement gauges enables everything from excitation to analysis as well as the explanation of phenomena.

4. Conclusions

In this paper, we have introduced two types of experimental teaching materials for the encouragement of reinforcing wooden houses: one is Hand Cart BURURU employing a cart and single-story wooden house model which is nondestructive and scaled down, and the other is Wooden House Collapse BURURU with 2-story wooden house models which are destructive and scaled down. Since these teaching materials can demonstrate how a wooden house shakes and collapses when an earthquake occurs, we are confident, through various activities, that they have a significant educational effect. We also believe that Wooden House Collapse BURURU is an effective teaching material in reinforcement encouragement because it can demonstrate the effect of each reinforcing pattern. We have made a DVD which includes a teaching video and a PowerPoint file. The video, "Model Experiments Showing Key Points for Reinforcing Wooden Houses" was made by arranging videos showing experiments with Wooden House Collapse BURURU and the PowerPoint file provides a description.

We expect that the teaching materials we developed will be able to contribute to the progress of building reinforcement in Japan. We will continue to develop teaching materials for antiseismic promotion. Readers with ideas or opinions on ways we can improve our materials should feel free to contact us.

Acknowledgements

We thank Kimio Ogura and Tetsuo Hara (OYO Seismic Instrumentation) very much for their help in developing the shaking cart and specifications for the model's joints. We also thank the parties concerned including local governments and disaster prevention leaders for their good advice.

[5] Oyo Seismic Instrumentation Inc., M. Eng.