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Development of Vibration Experiment Education Materials for Promotion of Seismic Retrofitting

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This paper introduces a series of vibration experiment education materials called "BURURU." The materials have been developed for teaching structural dynamics in universities and enlightening the public about disaster prevention. The series comprises: "Hand-rotated BURURU," which is a handy shaking table box; the electric powered version "Electric BURURU"; "Small Shaker BURURU," which is used for harmonic excitation of a model; "Hand Cart BURURU," which uses a hand cart as a shaking table; "Electric Cart BURURU," which is controlled by arbitrary input waves; "Wooden House Collapse BURURU," which shows the difference of collapse mechanisms due to seismic retrofitting; and "Paper BURURU," which is a paper model.

Key words: Education, enlightenment, seismic retrofit, structural dynamics, vibration experiment, shaking table, hand cart, paper-craft, collapse

1. Introduction

Many seismic disasters followed the Southern Hyogo Prefecture Earthquake and have caused increasing apprehension that an earthquake could occur in the Tokai, Tonankai, Nankai, off-Miyagi, or Metropolitan areas. Accordingly, it is necessary to reinforce existing buildings and houses as soon as possible. In March 2005, the Central Disaster Prevention Council announced its "Seismic Disaster Prevention Strategy" to attain a 50% reduction in disasters caused by an earthquake occurring in the Tokai, Tonankai, or Nankai districts and to give priority to the reinforcement of buildings and houses. However, progress is not good although many local governments have introduced support programs for seismic diagnosis and reinforcement. One of the reasons may be a lack of appropriate teaching materials for informing people of the necessity of building reinforcement.

In recent years, technologies for positively controlling the seismic characteristics of buildings, such as vibration isolation and control, have been increasingly used. Accordingly, it is essential to understand the seismic characteristics of buildings to be designed and there is an increasing need for teaching materials for building education and shaking experiments.

Through various disaster prevention activities[(1)-(2)] in local communities, many people have expected us to contribute to the development of a tool for encouraging building reinforcement. Therefore, we have listened to the needs of the people who participated in the activities and tried our best to make an appropriate tool by trial and error. Since desired teaching materials differ depending on educational scenes and purposes, we have developed various teaching materials of different sizes and with different behavioral mechanisms. Moreover, we have made videos and e-learning materials based on this equipment.

In this paper, we describe the outline of the teaching materials we have made as well as the structure and usage of each material. We also try to analyze the utilization status and effects as far as possible.

2. Outline of teaching materials for seismic experiments

We generally call the series of teaching materials introduced in this paper "BURURU." The first version is the portable shaking table "Hand-rotated BURURU," which we developed in 2000. This shaking table is kept in a duralumin suitcase with various experimental models. Turning the handle gives translational motion to the table. Thinking that a familiar name was important, we named it BURURU, a Japanese word meaning shaking in English. BURURU is also a combination of the Japanese words "hakoBU," "mawaRU," and "yureRU," which mean "carrying," "rotating," and "shaking" respectively in English[(3)].

The first version of BURURU created a sensation because this type of teaching material was not available at that time. Various groups asked us for educational activities with BURURU. Elementary school teachers particularly favored BURURU because of its simple hand-shaken mechanism, and it has played a key role in educational events such as the "Disaster Prevention School for Parents and Children[(4)]" held in Shizuoka Prefecture in 2002 and "Joint Parent and Child Seismic Disaster Prevention Education[(5)]" held in Aichi Prefecture from 2003 to 2004.

Hand-rotated BURURU has been put on the market, and, as shown in Figure 1, about 100 units are now used in various places all over Japan, such as universities, governmental disaster prevention and building bureaus, natural and science museums, volunteer disaster prevention groups, constructors, and housing makers. The universities use BURURU as a teaching material for the seismic engineering class, the museums demonstrate a building shaken by it, and the governmental bureaus use it to encourage the reinforcement of houses. The volunteer groups use BURURU to locally increase disaster prevention awareness, and the constructors and housing makers explain vibration isolation and control technologies with it.

We received a variety of direct and indirect opinions from these users. In short, they desired various kinds of BURURU. They wanted a portable, light-weight, and small-size one, a low-cost one, an electrically-powered one, a large-size one for use in a gymnasium, one with an exciter to shake the building's interior, and one to demonstrate house collapse. After hearing these opinions, we sent questionnaires to the potential users to grasp how BURURU would actually be used. The results of the questionnaires matched the opinions given above.

Accordingly, we decided to develop various teaching materials for seismic experiments based on the concept of the Hand-rotated BURURU[(6)]. Table 1 lists them as of now. We will first summarize them and then describe each teaching material in detail.

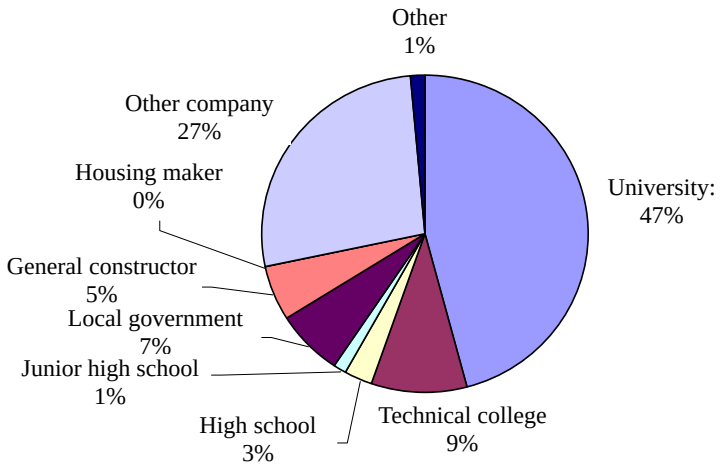


Figure 1 Users of the teaching material “BURURU”

(1) Hand-rotated BURURU[3]

This is the first teaching material with seismic models and has a mechanism of changing rotational motion to translational motion via a universal joint. Hand-rotated BURURU allows the user to feel vibration by turning the handle by hand. It has an inverted pendulum and 2-story frame model and enables various experiments, such as shaking, base isolation, and vibration control. Accordingly, it can be used in a wide range of fields from university classes in dynamics to experimental learning in elementary schools. This experimental equipment comes with model furniture and models for liquefaction and shear vibration of stratified ground.

(2) Electric BURURU

Based on Hand-rotated BURURU, Electric BURURU has a driver powered electrically. It can be used anywhere thanks to a built-in rechargeable battery, and easily demonstrates the difference between vibration isolation and control as well as the effect of unbalanced braces and walls on the shaking of a building. Because of its small size Electric BURURU is suitable for use in classrooms, and a projector can be used to show enlarged motion pictures.

(3) Hand Cart BURURU

This is a large-size teaching material developed for “Joint Parent and Child Seismic Disaster Prevention Education.” Because we often need to show BURURU to many people in a gymnasium, we made the bigger Hand Cart BURURU by altering a commercial cart. Children can stand on it to experience vibration first-hand, and it can be shaken with a wooden building model loaded on it to demonstrate the effect of the braces’ balance and roof’s weight as well as furniture falling down. The building model is nondestructive, and we first prepared only a single-story building but have now added a 2-story building. Because of its large size, Hand Cart BURURU is

suitable for disaster prevention training in a gymnasium.

Table 1 “BURURU” series demonstrating actual shaking phenomena

Name	Image	Operations	Characteristics	Use
Hand-driven BURURU		The handle is rotated by hand, and the rotary motion is converted into translation, which shakes the table.	Many types of miniatures are contained in an attache case easy to carry. Users turn the handle by hand, so they can really feel frequency characteristics.	It can be used at many occasions, such as lectures and events. As it offers visual explanations of oscillatory phenomenon, vibration theories can be learned more effectively.
Electric BURURU		It is driven by a motor, powered by a built-in buttery. The table shakes at frequencies specified by the dial.	As its vibration frequencies can be mechanically controlled, the table can be shaken in a constant and repeatable manner. The device is light and easy to carry.	It can easily imitate continuous changes of frequencies, and shorter and longer period motions, which are difficult for a hand-driven device to simulate.
On-cart BURURU		A cart used, ordinarily, to carry goods is equipped with a handle, which is pushed and pulled to shake the cart.	It is applicable to experiments with miniatures similar to wooden building, so it helps users really feel how effective seismic strengthening is. They can also see how decentering causes torsion. Children can stand on it to feel shakes.	It is useful in explaining how effective seismic strengthening is for wooden building in ways that ordinary people can easily understand it.
BURURU for collapsing wooden buildings		It has two different models of building on the cart, similar to that of the on-cart BURURU, and shows how different they are in ways they collapse.	Demonstrations can be carried out, for example, with or without braces and/or structural plywood, with different arrangements of walls, with or without metal connectors, with different weight of roofs, on soft or hard ground, with or without measures for preventing furniture from tumbling, and with or without concrete block walls.	It uses 1/10 scale models of conventional framework structure buildings to show how different they are in ways they collapse. It is the best tool for education about anti-seismic strengthening.
Self-propelled BURURU		It has batteries in it to power a servomotor, and imitates earthquake motions according to waveforms input.	It can replicate longer-period and longer-stroke earthquake motions, which cannot be mimicked by conventional shaking tables. Users can stand on it to feel shakes.	It is useful to have high buildings residents and those concerned feel how they shake and help them improve awareness.
Paper BURURU		The paper model house is swung by hand from side to side.	Participants by themselves build mocks and shake them, so that they can personally see how different buildings are in natural periods and what effects braces have.	It is an effective tool at participatory workshops, and a good souvenir at lectures. It can also be used to have children interested in how buildings shake.
Small BURURU		The shaking machine has a battery in it, and generates horizontal vibrations. The frequency can be changed with a dial.	It can be placed on a small mock, and shake it. The device has the resonance curve understood in an effective manner.	It can be used to explain principles of vibration tests, which are often carried for vibration testing of buildings.

(4) Wooden House Collapse BURURU[7]

We developed this teaching material to help us describe the key points for reinforcing wooden houses while conducting a collapse test. Adjusting the shaking table of Hand Cart BURURU enables two finely crafted 2-story building models with a scale of 1/10 to be loaded and shaken simultaneously. Wooden House Collapse BURURU can show how the models collapse depending on the balance of braces, the weight of the roof, the availability of joints, the quality of the ground, and the presence of anchors pounded into the base. The models can be reassembled but it takes a long time to do it, so a video is necessary to show the building collapse. Wooden House Collapse BURURU is mainly used in housing fairs hosted by administrative agencies or on TV programs in order to encourage the reinforcement of houses.

(5) Electric Cart BURURU[8]

We developed this version by modifying an electrically powered cart. The purpose of Electric Cart BURURU is to demonstrate the interior shaking of a building over a long-period. It can generate long-period and large-amplitude vibration, which general shaking tables have never produced. We use the base of an electrically powered cart and install a function generator and servomotor to generate an arbitrary waveform.

(6) Paper BURURU[8]

This is a paper house model kit that allows children to easily understand the key points and the need for reinforcing houses while making the model by themselves. Even children can fabricate the perforated cardboard model in about ten minutes, provided they have double-sided adhesive tape. Paper BURURU is very effective in seismic events and elementary/middle school classes because participants can understand the importance of the roof's weight and braces' balance while making and shaking the model. About 10,000 kits are already in use.

(7) Small Shaker BURURU

This is a shaker with a micro eccentric mass. Putting it on the model of Hand-rotated BURURU and conducting a shaking test can demonstrate a resonance curve. The trigger for developing Small Shaker BURURU was to show residents the reason why an experiment with an exciter was necessary in an atomic power generation plant. We used it with Hand-rotated BURURU to show common resonance caused by earth motion and the shaker. Because of a variable frequency function, Small Shaker BURURU is suitable for describing resonance curves and vibration modes in lectures on modal theory.

3. Hand-rotated BURURU

Hand-rotated BURURU is a portable shaking table, the appearance of which is shown in Figure 2(a). A duralumin suitcase contains many experimental models, as shown in Figure 2(b), and a manually shaking table indicated in 2(c). The size is 470 × 320 × 200 mm and the weight is about 10 kg.

Figures 2(d)-(e) show the structure of the shaking table, which has a mechanism of transforming rotational motion to translational motion via a universal joint. Turning the handle at the front of the case sinusoidally shakes the table in a horizontal direction. Built-in gears switch the rotation speed between once and triple. The table size is about 360 × 190 mm and the vibration amplitude is about ±0.5 or ±1.5 cm. When turning the handle at the first speed, the user can feel the real vibration because the number of revolutions agrees with the frequency of the shaking table.

Most of the built-in models are made from stainless steel, and they are (f) 3 inverted pendulums with mass positioned variably, (g) 6 weights—3 pairs weighing the same—for the pendulum, (h) a 2-story frame model and 2 sets of a removable roof and shear wall, and (i) 2 kinds of isolators—2 of each—and 2 rollers installed in the foundation.

In addition to the above, Hand-rotated BURURU has ground and interior models, which are (j)(l) a ground model replicating a shear vibration, (k)(m) a liquefaction model filled with glass beads, and (n) a furniture collapse model. The last model is a 1/10 scale interior based on GURAGURA-KUN developed by Nagoya Fire Fighting School[9].

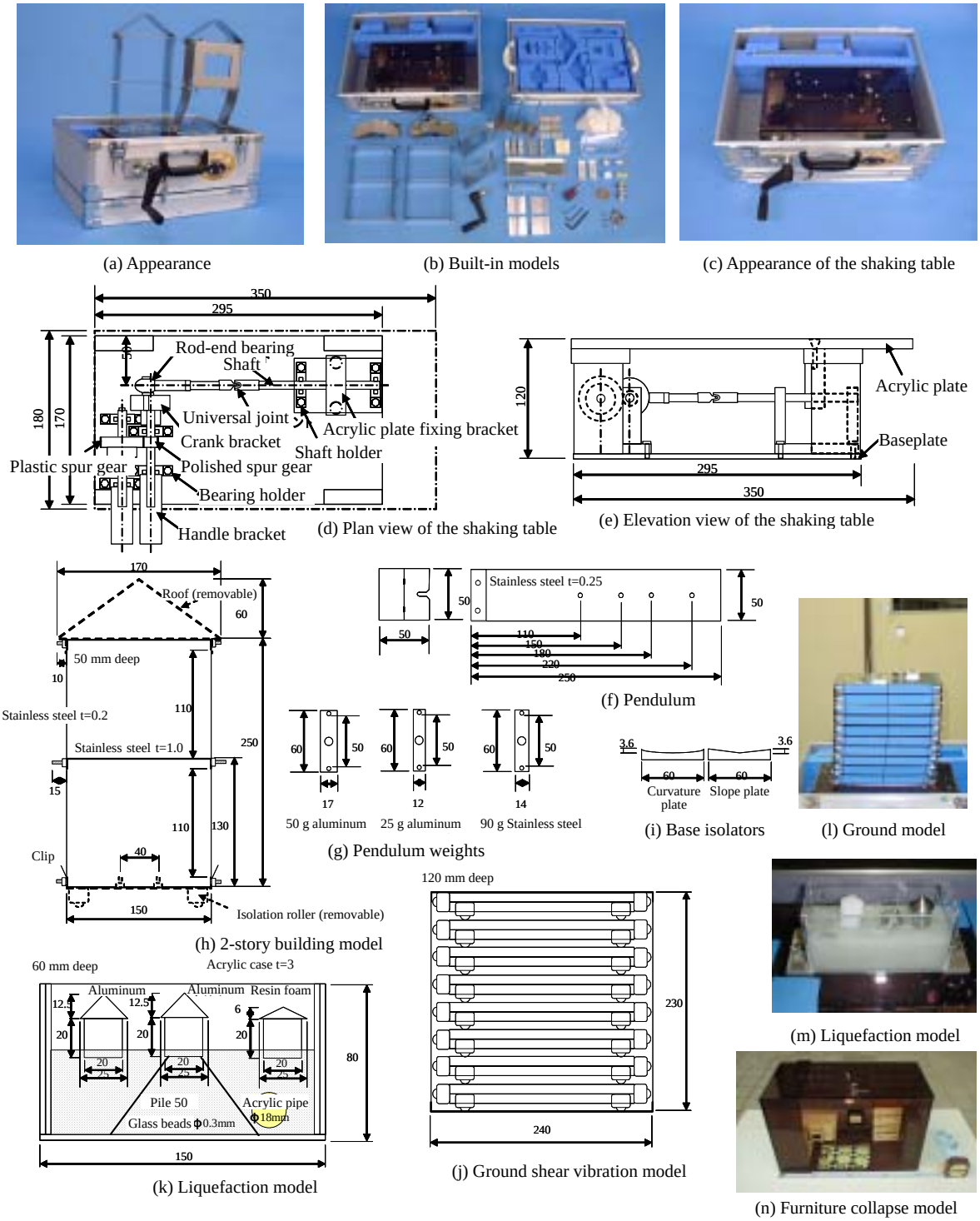


Figure 2　Outline of the shaking table and models of Hand-rotated BURURU

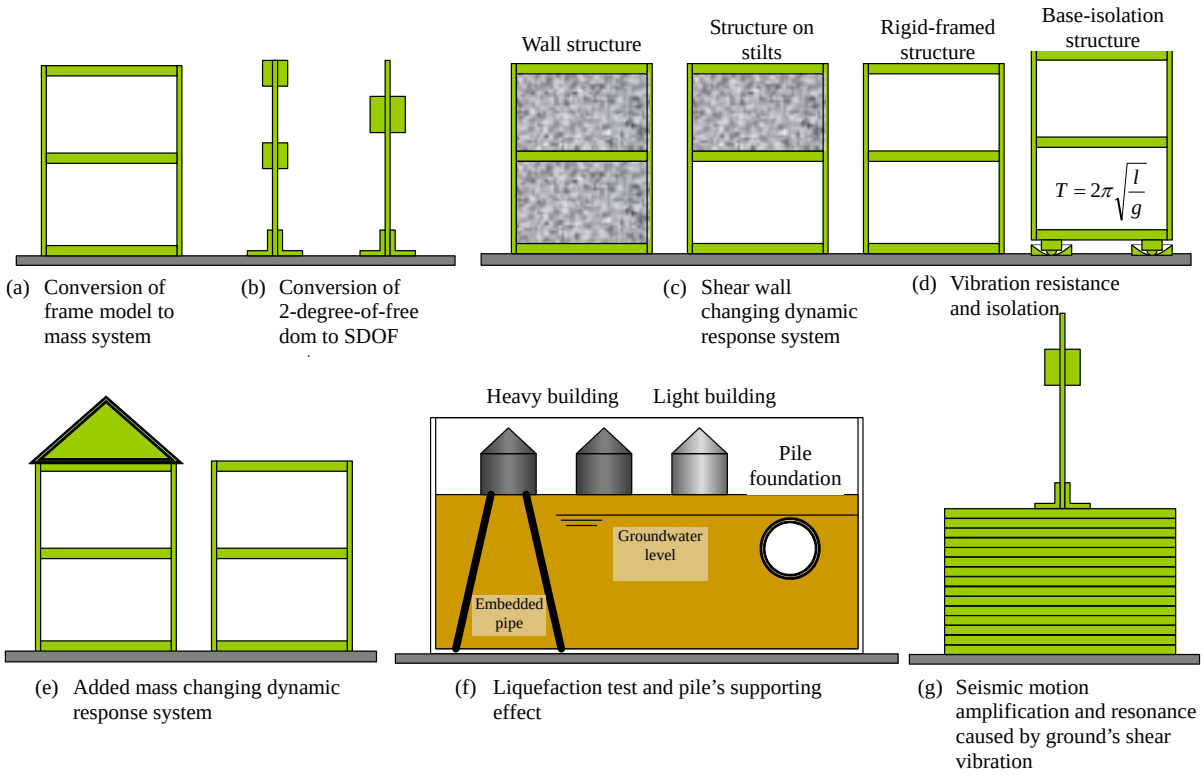


Figure 3 Shaking experiments with Hand-rotated BURURU

As shown in Figure 3(a), putting multiple models on the table and shaking them can allow comparison of the vibrations of each model. Figure 3 shows experiments with the built-in models. Hand-rotated BURURU can demonstrate various mechanisms, such as the natural frequency, eigenmode, and resonance of a building, the conversion of a frame model to a mass model, how to install shear walls, changes in vibration caused by the weight of a roof, the principles of various vibration isolators and controllers, liquefaction principles, the role of a pile foundation, the shear vibrations of the ground, the ground amplification, and the resonance of the ground and building.

Moreover, Hand-rotated BURURU offers various possibilities, such as a lecture on vibration or seismic engineering in the architecture or civil engineering department of a university, a description of base isolation, vibration control, and liquefaction given by a constructor or housing maker, the encouragement of seismic diagnosis/reinforcement and a description of tips for improvement given by a local government, and a class on shaking in an elementary or middle school.

Hand-rotated BURURU increases the users' interest in vibration by allowing them to handle the apparatus and sense the shaking phenomenon for themselves. Figure 1 shows the various users. Hand-rotated BURURU is used mostly in schools as well as natural and science museums. Responses to our questionnaire tell us that Hand-rotated BURURU is too heavy, too expensive, hard to install, and troublesome after a liquefaction test. Accordingly, we will address these problems in an attempt to improve it.

4. Electric BURURU

This is the electrically-driven version of Hand-rotated BURURU. Featuring lighter weight and ease of use, Electric BURURU can be carried anywhere for educational activities. Figure 4 shows the appearance. The weight is about 3.5 kg—much lighter than Hand-rotated BURURU—because of a plastic case and models. The size is about 485 × 250 × 230 mm—similar to a shoulder bag.

Electric BURURU employs the same mechanism as Hand-rotated BURURU—it changes rotational motion to translational motion. If AC power is not available, a built-in battery can run this shaking table outdoors for a long time. The dimensions of the table are about 295 × 170 mm and the displacement amplitude is ±5 mm or less. The frequency is variable from 1 to 8 Hz. Figure 5 shows the shaking table. The dial located in the lower right changes the frequency arbitrarily.

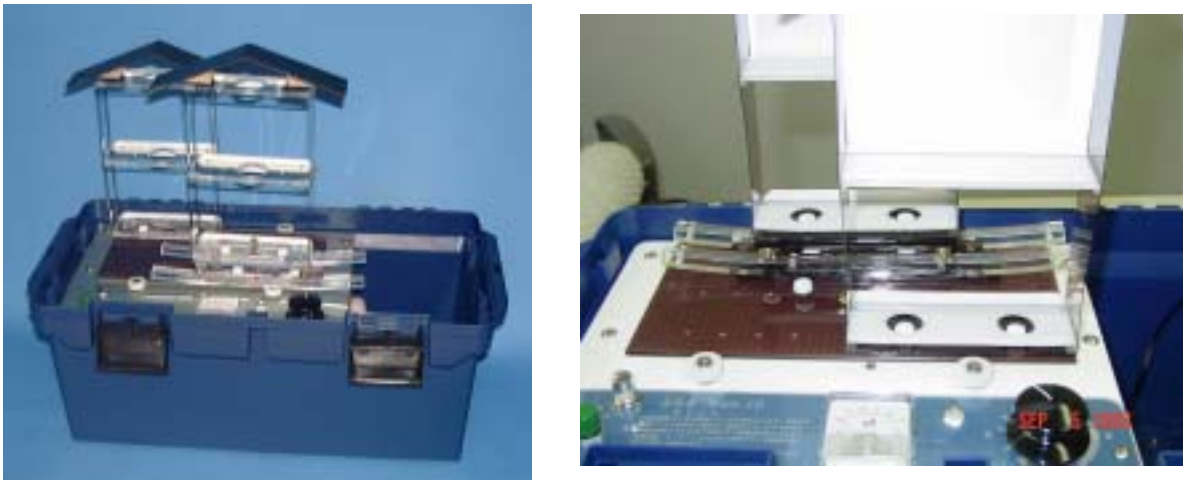


Figure 4 Appearance of Electric BURURU (left) and enlarged view of the isolator (right)

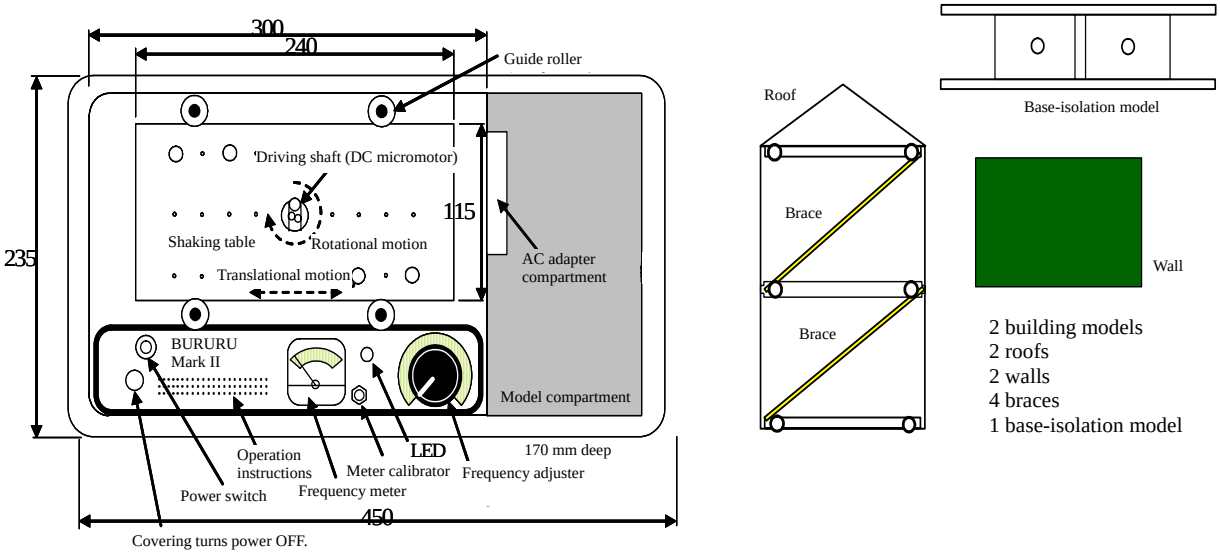


Figure 5 Shaking table and models of Electric BURURU

To be precise, a disk is fixed onto the shaft of a DC micromotor, a pin is fitted r mm apart from the center of the disk, and a very small ball bearing is secured onto the pin. The shaking table has a split in its center and the bearing is placed in it. As a result, the rotational motion of the disk is changed to the translation motion of the table without resistance caused by sliding friction. The mechanism generates a sinusoidal-wave vibration with a displacement amplitude of ±r. The DC micromotor is rated at an output power of 12 W, a voltage of 6 V, a maximum speed of 7,000 rpm, and a maximum torque of 16 mNm.

The accessories include a plastic pendulum, 2-story building model, brace, shear wall, and isolator. Electric BURURU can help the user understand resonance, the effect of the roof's weight and walls' balance on the upper and lower stories, and vibration isolation principles.

Note that we developed Electric BURURU as a tool for supporting preparedness leaders involved in disaster prevention activities in Aichi Prefecture. Since 2002, Aichi Prefecture has run the "Aichi Disaster Prevention College" to train 250 preparedness leaders every year. Graduates are given the title of Aichi preparedness leader and as members of the Aichi Preparedness Leader Association, take the initiative in disaster prevention activities with local voluntary groups. In cooperation with the Training Group, the Aichi Disaster Prevention Bureau, and the Aichi Preparedness Leader Association, we help the leaders perform their educational activities by, for example, creating a set of picture cards to explain Electric BURURU and the importance of antiseismic performance or giving the leaders a seminar on how to use Electric BURURU.

5. Hand Cart BURURU

This is a teaching material developed for showing a shaking test to many people, for example, in a seminar at the gymnasium of an elementary school. Developing Hand-rotated BURURU involved us in "Disaster Prevention School for Parents and Children[(4)]" held in Shizuoka Prefecture in 2002 and "Joint Parent and Child Seismic Disaster Prevention Education[(5)]" held in Aichi Prefecture from 2003 to 2004. We made Hand Cart BURURU after sensing the need for a large-size demonstrative teaching material for schoolchildren.

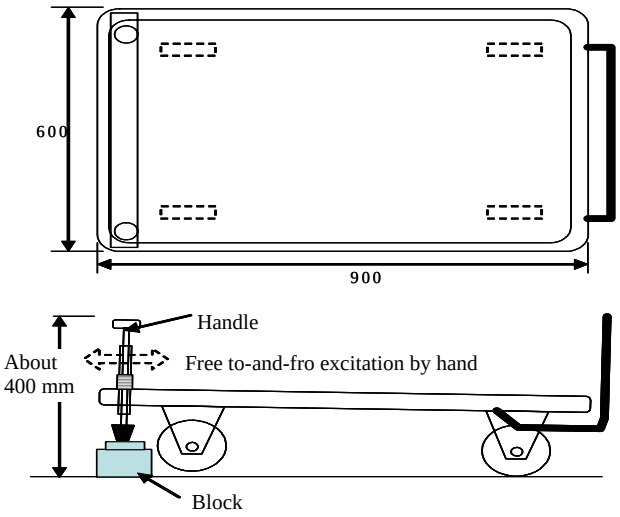
As shown in Figure 6(a), we made the shaking table by adapting a commercial cart. We installed a driving shaft with play at the end of the cart and put it on a block. Moving the handle to and fro gives horizontal reciprocating motion to the cart.

Apart from the large wooden building model, a schoolchild can also be loaded on the cart, as shown in Figure 6(b), which allows him or her to directly feel the vibration. Compared with a shaker vehicle, hand shaking can generate a more real and flexible vibration, and we can demonstrate how scary resonance is by shaking the cart at the natural period of the schoolchild loaded.

At the beginning, we prepared only a single-story wooden model. As shown in Figure 6(c), this is a 1/10 scale model and has very simple structure. The 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 Figure 6(e) to let them deform at the joint easily. Packed in a case as shown in Figure 6(d), the model is presented as a kit so that children can make it while learning the role of each component.

When using the first version, we realized there was a great need for a 2-story building model, so we additionally developed the 2-story wooden building model shown in Figure 6(f). For a furniture collapse test, we prepare miniature toy furniture.

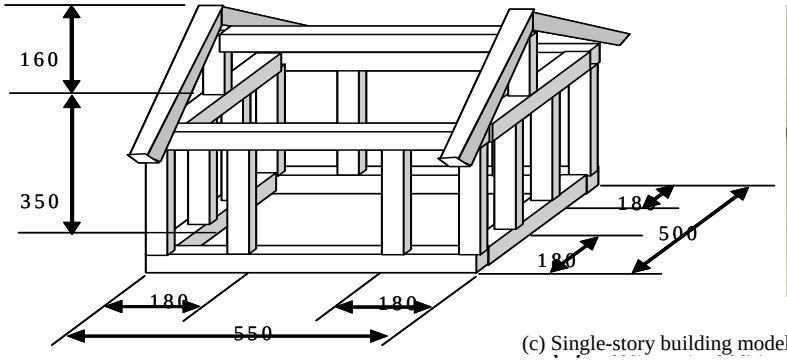
Using these models with Hand Cart BURURU can concretely demonstrate the importance of a lighter roof, balanced braces and walls on the upper and lower stories, flatly balanced walls, anchors pounded into the base, and reinforcement as well as the significance of measures against furniture falling down.



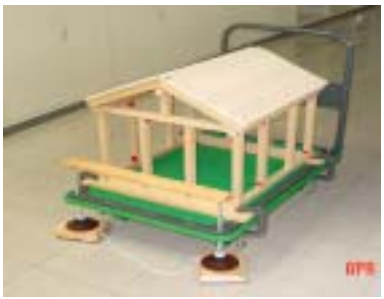
(a) Schematic diagram of the cart

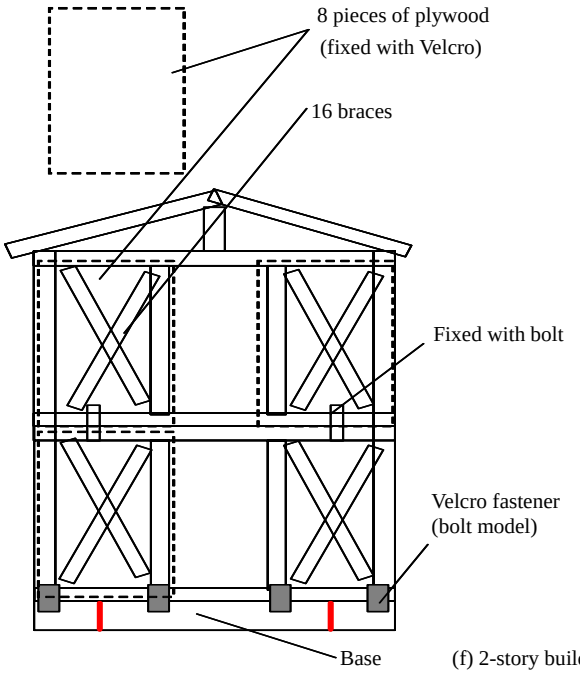
(b) Experiencing vibration

(d) Packed models

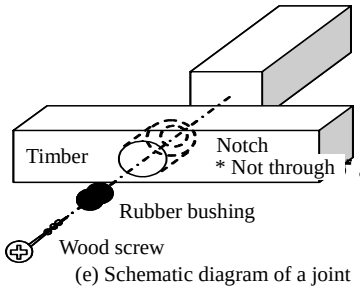


(c) Single-story building model





(f) 2-story building model



(e) Schematic diagram of a joint

Figure 6 Shaking table and models of Hand Cart BURURU

When conducting a test, we recommend that the educational effect is made greater by combining the test with photos showing a wooden house collapsing, experiments with Hand-rotated and Electric BURURUs, model fabrication with Paper BURURU, or videos demonstrating Wooden House Collapse BURURU.

Hand Cart BURURU is effective in disaster prevention education at elementary school events. It can be loaded in a van, and one of the authors has already conducted disaster prevention education at more than 40 elementary schools. Moreover, many disaster prevention leaders and volunteers ask us to lend them Hand Cart BURURU.

6. Wooden House Collapse BURURU

Use of Hand Cart BURURU proved that the shaking cart was effective, but local government users particularly desired that the promotion of reinforcing wooden houses had to show the difference between the collapse of reinforced and non-reinforced buildings. Accordingly, we developed Wooden House Collapse BURURU based on the concept of Hand Cart BURURU. It can (1) reproduce a typical wooden house disaster caused by an earthquake precisely, (2) allow easy comparisons of vibrations and collapsing states caused by various structural problems, (3) be carried easily for demonstrating several patterns at once.

Assuming a conventional 2-story framed building about 3.6 m wide and 5.4 m long, we make two 1/10 scale wooden models. Considering past wooden house disasters, we designed the models so that the joints break first. Two buildings with different structures can be loaded together on the shaking cart.

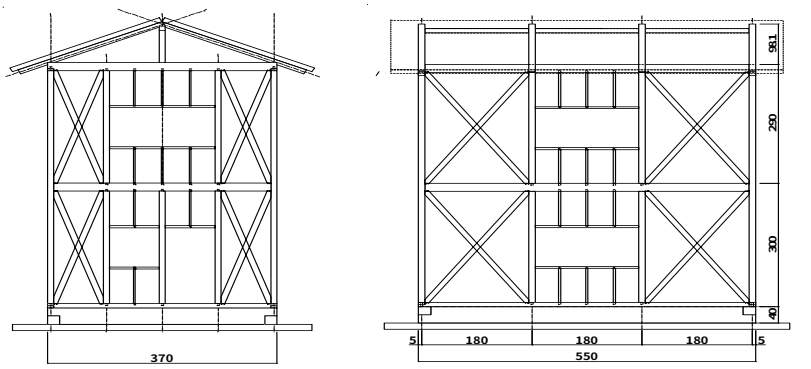
Figure 7 shows the outline of a model that employs Japanese cypress members for the columns, beams, braces, studs, and lintels as well as ash members for the base. Note that to simulate the breakdown of a house, we make 4 balloon framing columns at the corners and laths of balsa. A plastic tenon is attached to each column and Velcro fasteners substitute for metal brackets joining 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.

The law of similarity estimates that the model has one-third the natural period of a real building, but we adjust the joint stiffness to bring the former close to the latter. This is because we want to show the user as real a collapse as possible.

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.

Figure 8 is the scene of an experiment with Wooden House Collapse BURURU. Reinforced and non-reinforced buildings are shaken simultaneously to demonstrate the differences between their collapse mechanisms. It is effective to shoot the collapsing scene with a camcorder and then describe the causes with a slow-motion replay.



South elevation East/west elevation

Figure 7 2-story building model for Wooden House Collapse BURURU

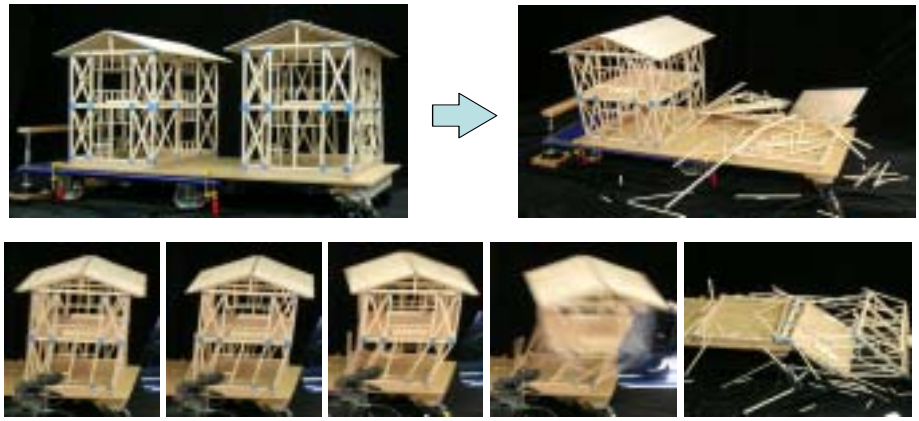
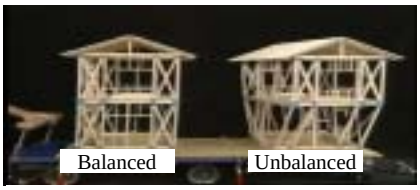


Figure 8 Collapsing process of a model

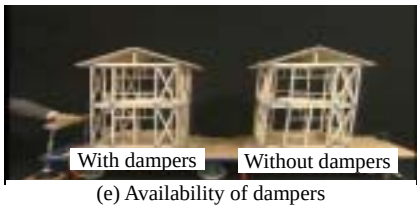
(a) Availability of brace

(b) Availability of joint

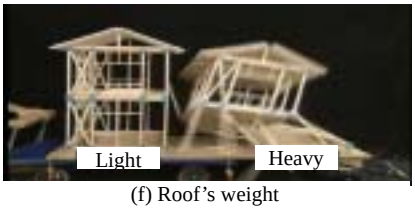


(c) Horizontal balance of wall

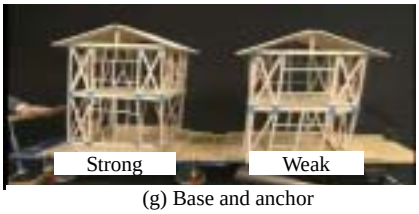
(d) Vertical balance of wall



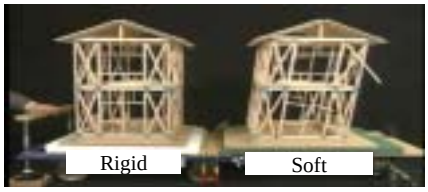
(e) Availability of dampers



(f) Roof's weight



(g) Base and anchor



(h) Ground

Figure 9 Experimental patterns for Wooden House Collapse BURURU

Figure 9 shows experimental patterns, which include (1) the availability of braces, (2) the availability of joints, (3) horizontal balance, (4) vertical balance, (5) the availability of dampers, (6) the roof's weight, (7) the quality of the base, and (8) the quality of the ground.

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. Accordingly, Wooden House Collapse BURURU has been mainly used in TV programs and at housing fairs for encouraging the reinforcement of houses[(10)].

As a supplemental material, we have made a teaching video titled "Model Experiments Showing Key Points for Reinforcing Wooden Houses" by arranging the videos of the experiments mentioned above and adding narration. Close-ups and slow-motion replays of the video can increase the educational effect. Moreover, we have created a PowerPoint file and a set of picture cards to show how to use Wooden House Collapse BURURU.

7. Electric Cart BURURU

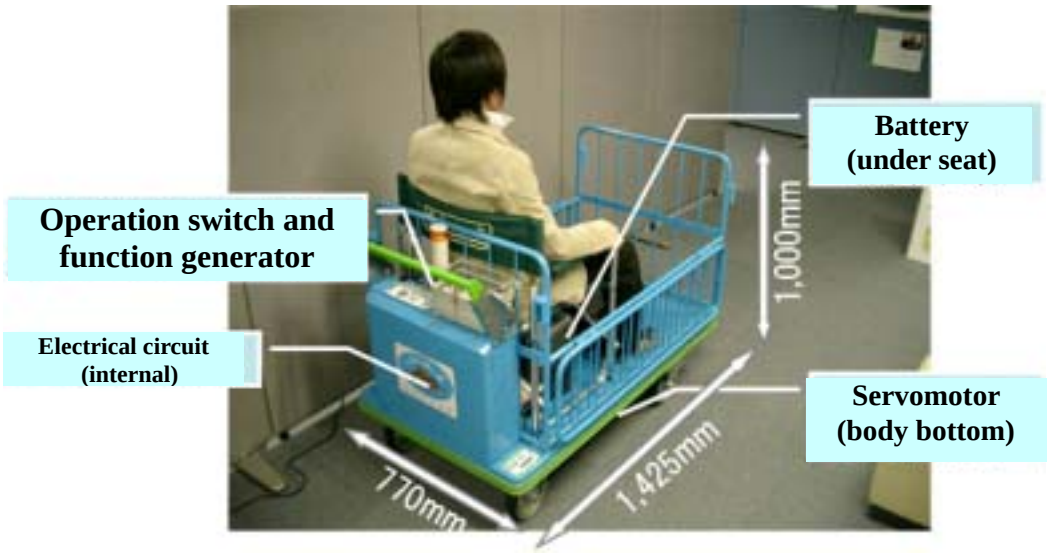
The concept of Hand Cart BURURU stimulated the development of a cart able to be driven electrically and controlled by an input waveform. The purpose of Electric Cart BURURU was to reproduce the interior shaking of a long-period structure like a high-rise building when a huge earthquake occurred—a long-period vibration continuing for a long time. Equipment able to demonstrate real vibration to building owners and users is essential to encourage the reinforcement of long-period buildings and interior measures against earthquakes. Conventional fixed shaking tables with actuators were much too big and had a stroke limit. Accordingly, we decided to develop a shaking cart able to be driven electrically and controlled by an input waveform. As shown in Figure 10(a), Electric Cart BURURU can be driven by a built-in battery and a person can be loaded on the cart, which means that the user can experience a long-term vibration anywhere.

Figure 10(b) illustrates the basic structure of Electric Cart BURURU, which was born by altering the motor and controller of an electrically-powered cart. The driver consists of a function generator, servo amplifier, motor driver circuit, gear head, servomotor, and encoder.

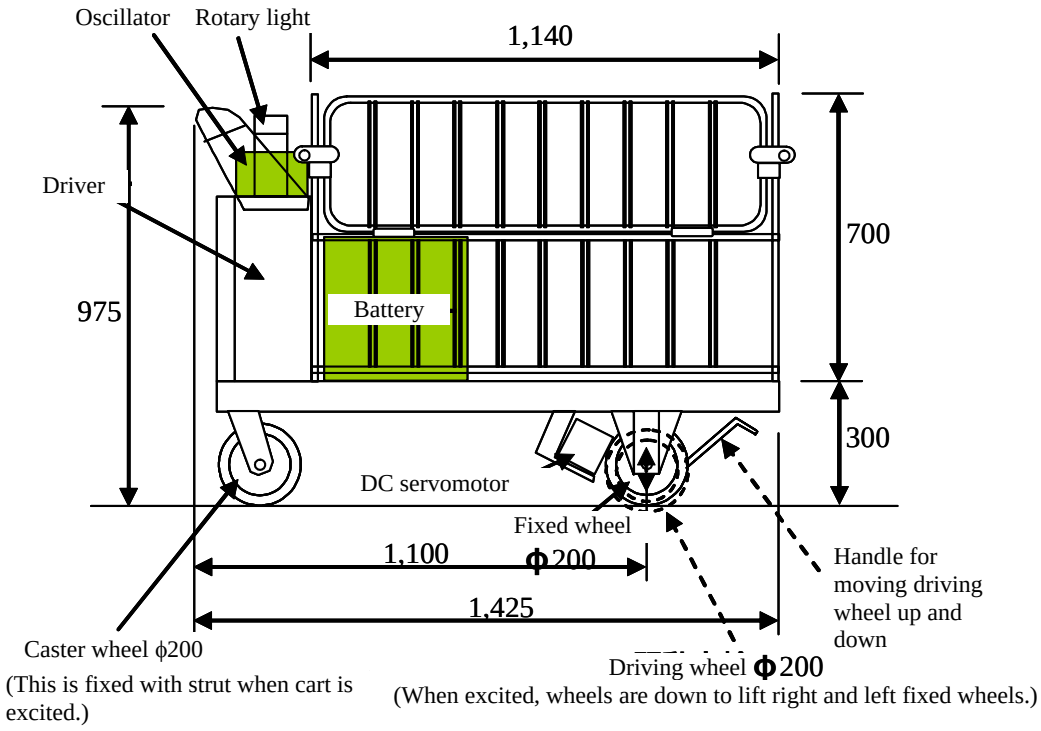
The servomotor is a pulse-modulated DC motor rated at an output power of 250 W. The servomechanism comprised of the motor and amplifier realizes a revolution synchronized with an input signal. The encoder is a sensor that converts a rotating angle to a digital value. It feeds the motor's speed back to the servo amplifier to generate a pulse train with a pulse width that changes depending on the input voltage, resulting in the desired number of revolutions. The motor driver circuit is a large-current power supply unit that drives the motor by amplifying a small signal derived from the servo amplifier. The motor drives the wheels via the gear head rated at a reduction ratio of 51:1 and a maximum intermittent torque of 180 N/m.

Electric Cart BURURU acts as follows: The function generator first outputs an electrical signal. Secondly, the servo amplifier pulse-modulates the signal and drives the motor via the motor driver circuit. When the motor rotates, the servo amplifier regularly generates a pulse with a width that varies depending on the feedback signal from the encoder. The servo circuit derives a differential pulse from the feedback and rotational pulses for the feedback

circuit to correct the motor speed. As a result, Electric Cart BURURU follows an input waveform with high fidelity.



(a) Appearance of Electric Cart BURURU



(b) Structure of Electric Cart BURURU

Figure 10 Appearance and structure of Electric Cart BURURU

Inputting 4,096 digital values into the small-size DC-powered function generator can generate an arbitrary seismic waveform. Figure 11 shows the results of inputting the El Centro wave and says that the output almost reproduces the input.

The current prototype is too heavy and too large to carry by van, but cargo transportation is possible. Because it has a built-in battery and charger, Electric Cart BURURU can be used anywhere regardless of the availability of an AC power supply, but, due to the single servomotor, the exciting force is insufficient. A performance test shows that the prototype can generate a vibration having 1 m or over in half amplitude when the period is 5 seconds or over, but the maximum velocity and acceleration are about 100 cm/s and 200 cm/s^2 respectively.

This shaking cart is inexpensive and can be easily used in a room to conduct a horizontal shaking test provided 100 V power supply is available. It is a mobile type, which makes movement and transportation easy. Accordingly, Electric Cart BURURU can be used as an experimental shaker for education. Since it can reproduce various vibrations, interlocking it with a PC allows participants to experience a predicted earthquake by first finding the shaking of their residential area according to the ground conditions, then deriving the seismic response of their houses from the number of stories, and finally producing the resulting vibration.

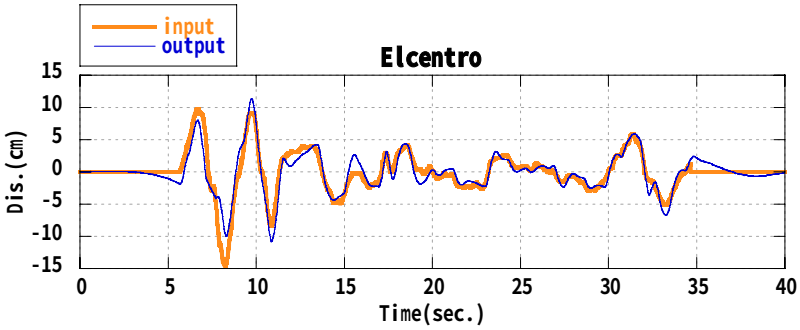


Figure 11 Waveform reproduced by Electric Cart BURURU

8. Paper BURURU

The teaching materials already mentioned are used mainly in seminars, lectures, and exhibitions, so the participants themselves, including the audience and pupils, have little chance to experience vibration. Accordingly, we have developed the paper-craft teaching material “Paper BURURU,” which allows participants to make building models by themselves to learn important points for reinforcing houses.

Paper BURURU is cardboard, both faces of which are printed. Figure 12 shows the front printed surface. The print is a replica of a 2-story wooden house that consists of columns, a floor, a base, braces, and a roof. A familiar sense of fun is incorporated in various places. The roof and braces on each floor can be removed from devised cut lines. This enables participants to understand the importance of braces and making the roof lighter by changing the roof’s weight and attaching/detaching braces on the upper and lower floors to change the vibration of the model.

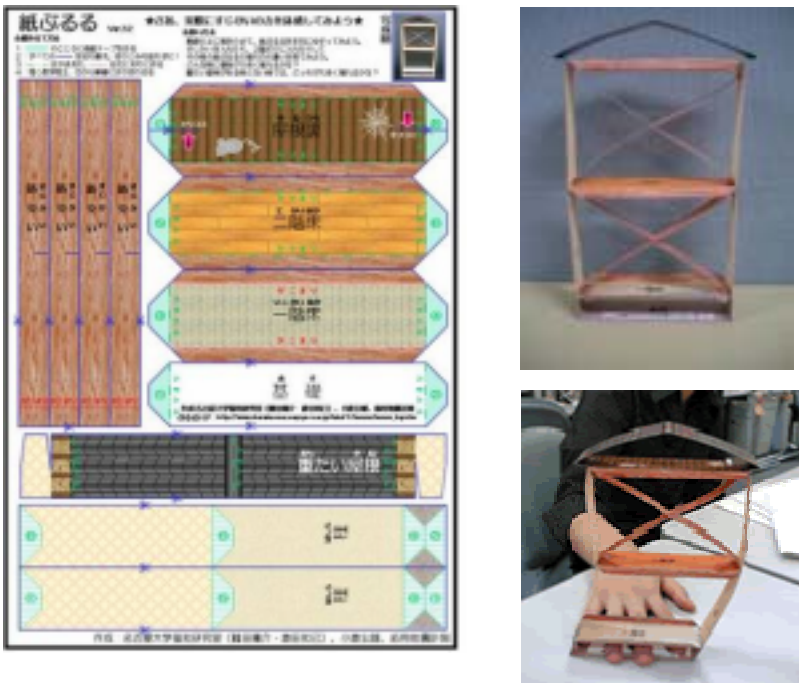


Figure 12　Cardboard of Paper BURURU

Figure 13　Paper BURURU and guide for making

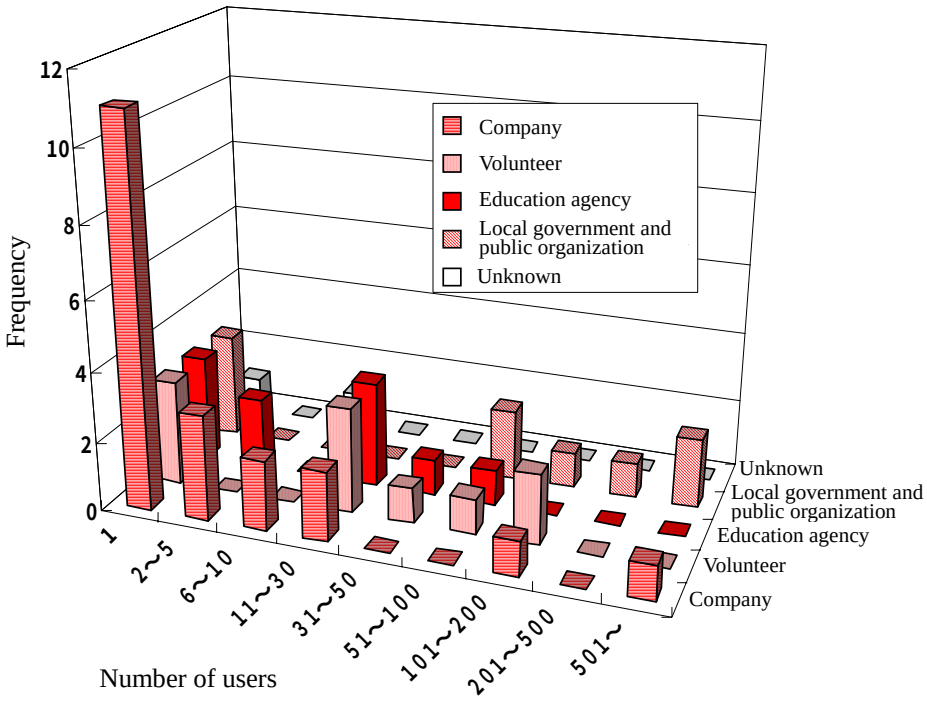


Figure 14 Users who downloaded Paper BURURU

We present Paper BURURU as a free PDF file on the website (http://www.sharaku.nuac.nagoya-u.ac.jp/laboFT/bururu/paper_bururu/kamibururu.html), therefore anyone can download it. To support the use of Paper BURURU, we also provide the assembly manual shown in Figure 13 and a user guide on the website. As shown in the photo in the lower right of Figure 12, even children can easily make the model and then shake it by moving their hand from side to side.

When developing Paper BURURU, we asked participants at various disaster prevention events to use the prototype, and repeatedly improved it by addressing the resulting problems. As a result, we currently present not only the free downloadable version on the website but also prepare the perforated cardboard version to allow people to use a large quantity of Paper BURURUs at events.

Paper BURURU has been used in various places. Even children younger than elementary schoolchildren enjoyed making it because they were interested in the paper-craft toy. We also found that even the lower grades in elementary schools were able to understand the effect of braces through the use of Paper BURURU. Paper BURURU had a significant impact when we first contacted educationalists about it and has acted as a helpful trigger to educational activities.

As of now, more than 10,000 Paper BURURUs are used, and the users include administrative agencies, enterprises, and voluntary groups. We present a questionnaire when people download the PDF file from the website to ask their purposes and opinions. Figure 14 shows the results.

The reason for the large number of individual users in companies is that employees may tend to want to try it out by themselves. When many employees use this teaching material, its purpose may be for the company to educate them for disaster prevention. Educational institute users are only elementary, middle, and high school students, which means that Paper BURURU may be used in school classes. Local governments and public organizations may use it in large quantities in disaster prevention events.

Direct opinions and results from questionnaires at schools and disaster prevention events say, "We understood the importance of the stiffness balance of the upper and lower stories well," "We enjoyed studying with the pretty model," and "We found something we have always wanted." Like these, many comments are in a good light. Users in local governments and public organizations also tell us that Paper BURURU has been very successful in large-scale events.

Because we have found this teaching material to be very effective, we will not only improve it but also make new related materials, such as prefabricated house, high-rise building, and furniture collapse versions.

9. Small Shaker BURURU

We developed this shaker for installation in a building model. The trigger to this development was a request to give audiences an easy-to-understand description of the mechanism of a shaker test conducted in an atomic power generation plant. We also thought that we needed a material suitable for describing a resonance curve.

As shown in the left photo of Figure 15, Shaker BURURU consists of an exciter and controller box. We expect the shaker to be used with Hand-rotated BURURU, and the right photo shows the shaker sitting on a model from Hand-rotated BURURU.

Shaker BURURU employs the same mechanism as a general-purpose exciter—two turntables with an eccentric weight rotate in the reverse direction to generate a horizontal exciting force. To be precise, a gear and one of the two turntables are fixed to the shaft of a DC micromotor, and the gear is engaged in the other turntable to reverse. As a result, an exciting force acts in a direction orthogonal to the two turntables.

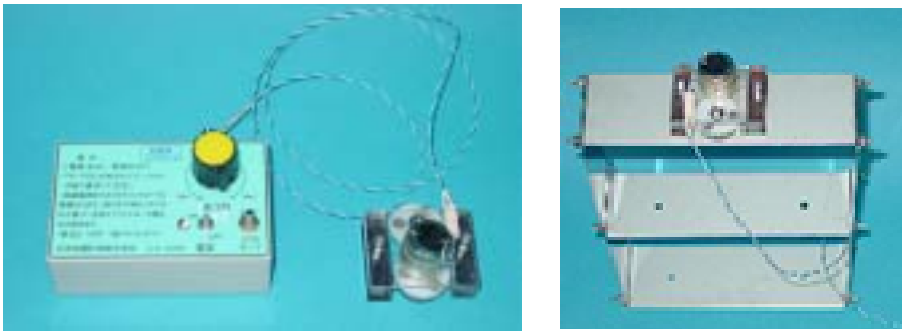
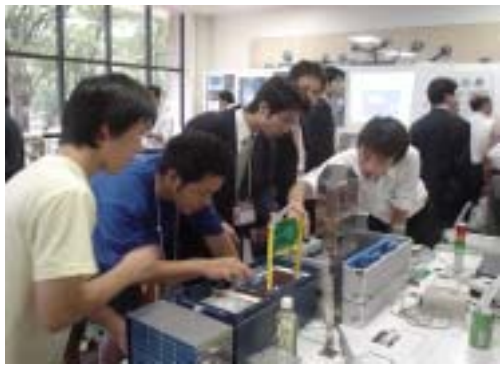


Figure 15 Small Shaker BURURU

(a) 2002 Disaster Prevention School for Parents and Children at Fukuroi-Nishi Elementary School, Shizuoka



(b) 2003 Convention and Exhibition “Structure Education with Seeing, Touching, and Feeling” hosted by Architectural Institute of Japan

(c) 2003 Joint Parent and Child Seismic Disaster Prevention Education at Yana Elementary School, Shinshiro-shi, Aichi

(d) 2003 Aichi Disaster Prevention Training at Kariya General Playground

(e) Disaster Prevention Seminar at Mikawa Hall, Fukuroi-shi, Shizuoka

(f) 2004 Joint Parent and Child Seismic Disaster Prevention Education at Unebe Elementary School, Toyota-shi, Aichi

(g) 2005 Aichi Housing and Reform hosted by Aichi Prefecture

(h) Building Research Institute’s booth in 2005 World Conference on Disaster Reduction

Figure 16　Disaster prevention education and activities with BURURU

To develop this shaker, we adjusted the mass very precisely and carefully selected a DC micromotor that was small and light but able to rotate smoothly at low to high speed. The micromotor is rated at an output power of 1.5 W, a voltage of 12 V, a maximum speed of 12,000 rpm, and a maximum torque of 1.2 mNm.

Shaker BURURU is energized by a built-in battery in the controller box. Turning the dial changes the frequency to demonstrate the resonance of a building.

The combination of Small Shaker and Hand-rotated BURURUs can clearly demonstrate that a resonance curve acquired by exciting the interior of a building is common to a transfer function given by earth motion. We experienced significant effects when using them in lectures on modal theory.

10. Educational activities with BURURU

The BURURU series presents various teaching materials for seismic experiments according to purposes—it can be used in multiple fields.

Applications include: as a teaching material for a class in seismic engineering, a mainstay of university building and civil engineering education; as a teaching material for retraining building engineers in vibration resistance, control, and isolation; as a tool for helping constructors or housing makers describe developed technologies to customers; as an educational material for seismic diagnosis and reinforcement encouraged by local governments; as an experimental and touchable material for science museums; as a supplemental teaching material used by disaster prevention leaders and volunteers; as a teaching material for a class in physics at high schools; and as a teaching material for disaster prevention education at elementary and middle schools. As mentioned before, BURURU is already used in various fields and users have responded to it favorably.

Figure 16 shows just some of the multiple activities we actively offered, including disaster prevention education at an elementary school, prefectural disaster prevention training, community disaster prevention activities at a public hall, academic meetings, housing fairs, and disaster prevention exhibitions.

While developing the teaching materials for seismic experiments, we have been making paper materials and our website to make the teaching materials more effective[(11)]. Figure 16 shows part of the BURURU website (http://www.sharaku.nuac.nagoya-u.ac.jp /laboFT/bururu/index.htm). In addition to the experimental teaching materials described in this paper, this site introduces video clips showing experiments with BURURU and the user manuals for each material.

In the future, we will upgrade this website to present e-learning materials for modal theory, seismic engineering, and disaster prevention education. As part of this effort, we are currently making an antiseismic promotion video of Wooden House Collapse BURURU with narration “Model Experiments Showing Key Points for Reinforcing Wooden Houses.”

(a) Top page of the BURURU website

(b) Page on which the BURURU family is introduced

Figure 16　Educational website with BURURU

11. Conclusions

In this paper, we have introduced a series of teaching materials for seismic experiments able to be used for university antiseismic education and local community disaster prevention activities. We have repeatedly improved them while using them in various activities and addressing problems encountered. Moreover, we have interacted with and listened to the needs of many people involved in school education and disaster prevention activities and have completed the teaching materials by trial and error.

We have developed each material according to different user needs and as a result are able to present a versatile lineup of BURURUs. Readers with questions or opinions should feel free to contact us. We would like to make improvements according to such opinions. In the next stage, we will not only develop more effective experimental teaching materials but also present e-learning-compliant ones for antiseismic and disaster prevention education to complement the BURURU series mentioned in this paper.

Acknowledgements