DEVELOPMENT OF VIBRATION EXPERIMENT EDUCATION MATERIALS FOR STRUCTURAL AND SOIL DYNAMICS

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ABSTRACT :

A series of dynamic vibration experiment and educational devices, collectively named 'BURURU' are developed to facilitate and improve education regarding structural and soil dynamics for university students and professional engineers, and to encourage seismic retrofitting among members of the general public by clearly demonstrating the effectiveness of such retrofitting. The BURURU series consists of various kinds of vibration-producing devices and building and soil models. Web-based simulation tools and other experimental materials are also developed and made available for specific purposes and/or objectives. Vibration tables of various types, sizes, and driving mechanisms, including small shaking platforms have been developed to serve as platforms for forced vibration testing. The devices utilize various pendulums, frame structures of different sizes, viscous dampers and base-isolation mechanism, soft soil to demonstrate soil amplification, structure interaction and liquefaction and even indoor furniture models. In order to support online virtual experimentation, a web-based, real-time dynamic simulator using FLASH action script is also available. It is felt that by showing various dynamic tests immediately after teaching the formulation of dynamics, students more easily understand dynamic phenomena, residents can fully comprehend the importance of seismic retrofitting, and all parties concerned can be expected to more enthusiastically work on concrete disaster prevention activities.

KEYWORDS: Education, Dynamics, Vibration experiment, Model test, Disaster mitigation

1. INTRODUCTION

Aseismic design based on earthquake response analysis is normally conducted solely for special structures such as super high-rise buildings, base-isolated buildings and nuclear power facilities. Because of this, many structural designers involved in the creation of aseismic buildings are unable fully understand the dynamic response of buildings.

University architectural education normally centers on statics and primarily structural mechanics, and there is little spare time available for education on dynamics. Generally, lectures on structural mechanics are accompanied with adequate exercises. In the case of statics, because simultaneous linear equations can be solved with consideration for equilibriums of force and displacement compatibility, complicated numerical formulas are not necessary. Moreover, because graphical methods have been developed and answers are easy to express as illustrations, students comprehend equilibrium of force, moment distribution, and deformation behavior comparatively well.

On the other hand, because universities do not have sufficient time to provide lectures on dynamics, and because dynamics require a strong foundation in advanced mathematical formulae (such as differential equations and Fourier analysis) students are rarely inclined to pursue such studies on their own. Furthermore, because those students do not spend sufficient time studying basic theory, they are unable to keep abreast with advanced lectures centering on formularization. Dynamic calculation is not well suited to written exercises and requires the use of computers. Therefore, students who are inadequately prepared, and who are disinclined to extensively review, are likely to drop out. Because dynamic phenomena cannot be expressed by still imagery, they are frequently explained using waveforms and spectra. Furthermore, it is hard to understand dynamic phenomena from graphs. To improve on this situation, it is considered to be more effective to use simple model experiments and simulators to support formularization and graphs.

As far as earthquake-resistant design of low damping and long-period structures such as super high rise buildings is concerned, unless designers have a proper understanding of resonance, they will be unable to grasp the importance of natural period and damping of buildings. And, unless they understand these factors, they cannot grasp the basic requirements for the design of super high-rise buildings, such as the avoidance of resonance and the addition of damping. In addition, they cannot fully comprehend that it is not just the amplitude of an earthquake that is important, the period or duration must also be considered for prediction of strong ground motion.

Recently, there have been an increasing number of buildings capable of artificially controlling their dynamic behavior by methods such as base isolation or vibration control. It is believed that if the principles of base isolation and vibration control are explained clearly, not only to the engineers but also to the owners of more conventional buildings, base isolated or vibration controlled buildings will become much more popular.

To facilitate this, it is necessary for everyone concerned to understand vibration phenomena correctly and to comprehend how buildings collapse. This will encourage students to study dynamics, engineers to adopt base isolation and vibration control based on dynamic phenomena, building owners to construct buildings with greater consideration for seismic safety, and residents to take the initiative in integrating earthquake countermeasures into their homes. Now is the time to shake off the traditional education style governed by the formularization of theories and the use of graphs of waveforms and spectra, and to firmly grasp new education methods.

In this paper, I will explain several examples of methods I have utilized. They center on simple vibration experiment tools designed for classroom use and a virtual experiment system available via the Internet. They are based on teaching materials that can effectively and plainly explain the dynamic behavior of buildings during an earthquake and illustrate clearly the details of how a collapse occurs.

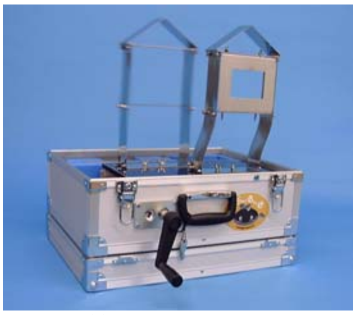
2. VIBRATION EXPERIMENT EDUCATION MATERIALS

The vibration experiment education materials explained herein are collectively called "BURURU." The first device developed was a hand-rotated portable shaking table consisting of a duralumin attaché case that incorporates a shaking table and various supplemental experimental materials. Once it has been set up correctly, rotating the handle by hand causes translational movements to the table, thus simulating the effects of an earthquake. This simple hand-rotated mechanism is suitable for demonstrating the period of vibration. The device created a great sensation when it was first unveiled and shortly thereafter we received numerous requests to demonstrate BURURU. At present, about one hundred units are in use by universities, government disaster prevention and construction bureaus, natural and science museums as well as house builders and construction companies. Universities use the device during lectures on earthquake engineering, museums use them to demonstrate building vibration, and government bureaus use them to promote public awareness of the need for seismic retrofitting among the general public. Furthermore, units are also used by house makers and construction companies to explain the principles of base isolation and vibration control technologies.

Following the introduction of the popular hand-rotated unit, we received various requests and suggestions from users, both directly and indirectly, for improved versions. As a result of those suggestions and requests a number of other versions have entered service, including a smaller, lighter, and more portable device and a less expensive one. Also available are an electric-powered model, a larger model suitable for use in a gymnasium, and even a small shaker that can be placed on the top of a model building. Some of the most popular are discussed below:

2.1. Hand-rotating portable shaking table

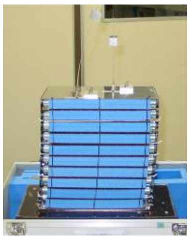
This was the first portable vibration experiment education device. It contains a mechanism that transforms rotary motion to translational motion via a universal joint. As shown in Figure 1, the table in the container is shaken right and left by hand-rotating the handle. The container contains various models, such as an inverted pendulum, two-story frame models, cross bracing, an earthquake-resistant wall, a base isolation device, a damper, and a soil liquefaction model. By using them in various combinations, it is possible to conduct experiments on seismic retrofit, base isolation, and vibration control as shown in Figure 2. The range of experiments possible include examining the effects of replacing a frame model with a lumped mass model, changing the period according to the height and weight of a lumped mass, examining the difference in period according to the number of building floors, the shapes of primary and higher modes, changes in the vibration mode and period



(a) Outer appearance

(b) Models contained

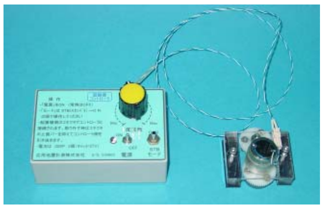
(c) Shaking table



(d) Model for soil amplification

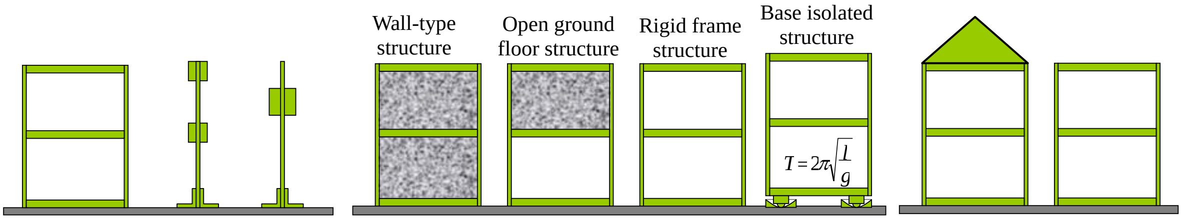
(e) Model for liquefaction experiment

(f) Model for falling of indoor furniture



(g) Small shaker

Figure 1 Outlines of the shaking table of Hand-rotating BURURU and related model



(a) Replacement of frame model with particle model

(b)Replacement of two-DOF's system to one-DOF system

(c)Change in dynamic characteristics by earthquake-resistant wall

(d)Seismic retrofitting and base isolation

(e)Change in dynamic characteristics by addition of mass

Figure 2 Examples of vibration experiment by hand-rotating potable shaking table according to the balance of rigidity of floors and the weight of the roof, the principle of base isolation, and the principle of vibration control.

To apply shaking energy to frame models, we have developed a small shaker that uses eccentric mass. Because it is possible to change its frequency, the small shaker is suitable for explanations about resonance curve and vibration mode during lectures on dynamics. Use of the shaker makes it easy to indicate the points common to the resonance by seismic ground motion and the resonance by the forced vibration.

There is also a model suitable for use during experiments on liquefaction, models for soft soil and layered soil, and a model for experiments regarding falling furniture. An experiment on liquefaction is carried out by setting up a light building, a heavy building, a pile-supported building, and buried pipes on simulated liquefied ground made of glass beads. Soft soil is used for experiments on soil-structure interaction, while the layered soil model is used to show shear vibration and resonance between building and soil. Indoor models are experimental tools for showing the effect of prevention of falling furniture.

Because this device has an interesting mechanism, it can be effectively used in a wide range of situations from university lectures to disaster prevention education at elementary schools.

2.2. Electric portable shaking table

This is an electricity-driven portable shaking table based on the same mechanism used in the hand-rotated device. A two-story frame model and base isolation device are prepared as shown in Figure 3. The vibration frequency can be adjusted by adjusting a dial. Because it is driven by rechargeable batteries and is light and small, it is easy to carry and is especially suitable for use in small classes.

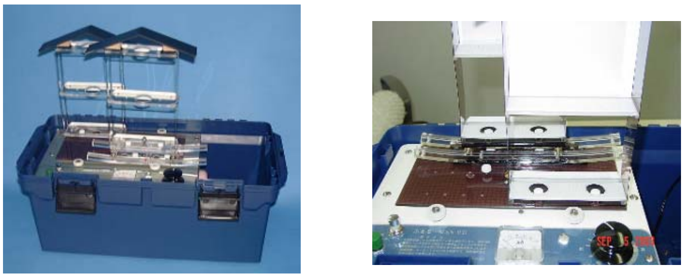


Figure 3 Outer appearance of electric portable shaking table and magnification of base isolation

2.3. Folding pendulum

This is a folding inverted pendulum used on the hand (Figure 4). Two or more weights that contain magnets are attached to a leaf spring, and the pedestal folds. Because of this, the folding pendulum can be carried in a pocket. The height, number, and weight of the weights can be changed freely, and a magnet sheet that functions as a friction damper is attached to the pendulum. It is also possible to add a base isolation device under the pedestal.

Figure 4 Folding pendulum

This enables vibration experiments with changes in spring constant, mass, and the number of masses; vibration control experiment with changes in damping constant; and base isolation experiments with a base isolation device. It is possible to make a seismic ground motion experiment by shaking the pedestal by hand and to make a free vibration experiment by fixing the pedestal on a desk, pushing the weights, and releasing the hand. In addition, by grasping the inverted pendulum tightly or softly, it is possible to reproduce hard rock or soft soil. Free vibration experiments clearly demonstrate that the period becomes longer and vibrations soon decrease on soft soil, showing the key point of soil-structure interaction. Although this is an extremely simple experiment, the essence of dynamic phenomena lies in a simple experiment.

2.4. Experimental education material that uses the cart-type shaking table

This is a large-scale education device we developed to demonstrate the shaking of a building to many children simultaneously in an elementary school gymnasium (Figure 5). A two-story wooden building model or a child is placed on the table, which is made from a cart, and shaken. With this device, it is possible to demonstrate the effects of laying a carpet of soft soil and to attach and remove cross bracing to or from the wooden building model. Furthermore, heavy and light roofs are included for use as attachments for other experiments.

(a) Two-story building model (b)Experiment for feeling of vibration (c) Feeling of long-period vibrations through tug-of-war

Figure 5 Shaking table and model of cart-type shaking table

This device is very effective for explaining the key points of seismic retrofit to the general public because it makes it possible to carry out experiments that confirm the effects of soft soil, the effects of rigidity balance among floors, the effects of rigidity eccentricity, and the effects of roof weight. Because the table is large, it is suitable for demonstration in gymnasiums or outdoors. In addition, it is also possible to reproduce long-period, long-stroke vibrations by tying ropes to both ends of the cart and pulling on them as if in a tug-of-war.

A collapsible model is also available for use with the device. By shaking two elaborate two-story wooden models (designed on a scale of 1:10) simultaneously, it is possible to show differences in the building collapse according to the balance of the cross bracing, the weight of the roof, the existence of metal joints, soil stiffness, the existence of anchor bolts driven into the foundation, and other factors.

Although the collapsed model can be reassembled easily, the reassembly takes a great deal of time so we also provide a video DVD that shows how the model collapses. There is also a “flip book” based on the video. Both the video of the experiments and the PDF data needed for making “flip books” is available on our website (http://www.sharaku.nuac.nagoya-u.ac.jp/laboFT/ bururu/index.htm).

The educational effect of the above is great because they show that even a small difference in structure causes a great difference in how a building will collapse. The lower right of Figure 6 is a photo of a collapse experiment carried out in the presence of former Prime Minister Koizumi. Furthermore, to promote the seismic retrofit of temples and shrines, we have prepared a temple model on the scale of 1:10. A reinforced concrete building model made of blocks and wires is also developed.

Because these education materials are easy to understand, they are frequently used during public events and on special TV programs that teach the importance of seismic building retrofitting.

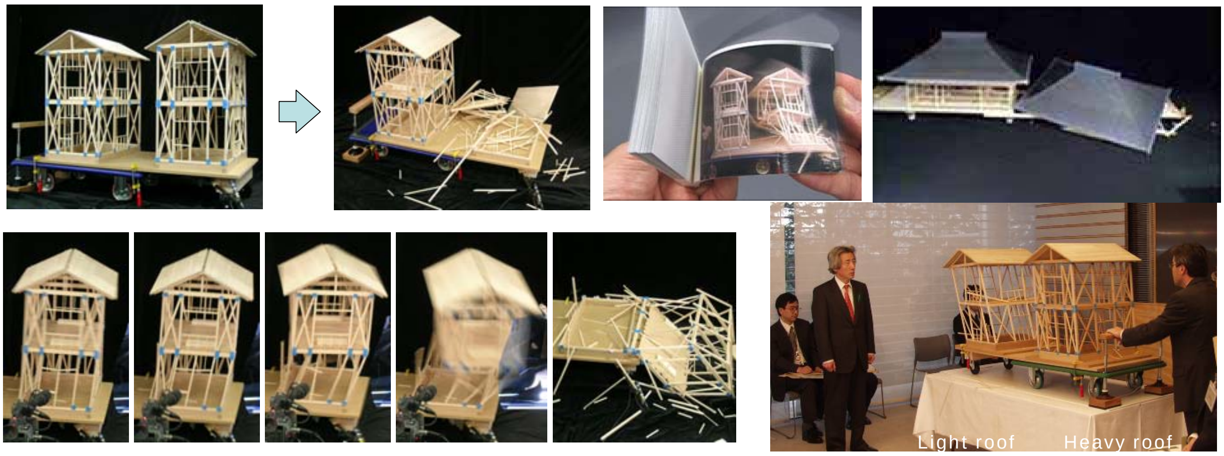


Figure 6 Models for experiments on collapse of wooden two-story houses and temples

2.5. Digitally-controllable shaking table

We have also developed three (two large, one small) digitally controllable shaking tables, using the same concept applied to the cart-type shaking table (Figure 7). One such table is a long-period long-stroke shaking table developed to reproduce a high-rise building's response to long-period seismic ground motions. It is called a "Triple-L Shaker" for Long-period Long-stroke Linear Shaker. The table cart is attached to a rail which is then pulled by right and left pulse motors. It can be shaken with a displacement of 3 m, velocity of 5 m/s, and acceleration of 20 m/s^2. This device utilizes a PC to calculate vibrations for a certain building type constructed on a certain ground and to reproduce them in quasi-real time.

(a) Long-period long-stroke linear shaker (Triple-L Shaker)

(b) Bi-lateral long-period long-stroke shaker (BiCURI)

(c) Desktop bilateral shaker (Note shaker)

(d) Scaled models of indoors and buildings for note-shaker

Figure 7 Digitally-controllable shaking tables

A bilateral shaker named 'BiCURI', based on a similar idea is also available. It can shake with displacement of 1.5m, velocity of 4m/s, and acceleration of 20m/s^2 for one direction and with displacement of 0.5m, velocity of 1.5m/s, and acceleration of 20m/s^2 for another direction.

We also developed a desktop digital-control bilateral shaker known as a Note Shaker. For this device, we attached a servomotor to a table that can move bilaterally, and made it possible to control vibrations digitally from the PC. This shaker is suitable for indoor experiments that utilize a small model. 1/25 models for typical rooms such as a bedrooms, children rooms and dining rooms, as well as a 1/50 model for a framed structure, are prepared for experimental use. These devices with small room models enable us to visualize realistic shaking scenery considering scaling law for size and time. Small size shaking experiment is done in compressed time scale and is taken by small CCD video cameras on the shaking table. Then, by projecting this video to the large screen with the real-size and enlarged time scale, the realistic experiment scene can be reproduced.

2.6. Paper building model kit

The purpose of this kit is to enable people to easily understand how a building shakes. It is made of perforated cardboard. Because double-sided tape is attached, the building model can be assembled in about ten minutes and it is possible to understand the importance of light roof weight and balance of cross-bracing and feel the effects of vibrations of a building. Although the model is basically a two-story building, it is possible to create a tall building model by stacking two or more such models together. Furthermore, if two cylindrical shaped pencils are put under the building, the building becomes base-isolated. This kit is very effective for events and lessons at elementary or junior high schools. Figure 8 includes a photo of former Prime Ministers Koizumi and Abe and other government ministers assembling "Paper BURURU." Anyone can download and use the original drawing and user's manuals from the "BURURU Homepage" (http://www.sharaku.nuac.nagoya-u.ac.jp/laboFT/bururu/index.htm).

Figure 8 Paper building model kit

3. E-LEARNING USING DYNAMIC SIMULATORS ON WEB-SITE

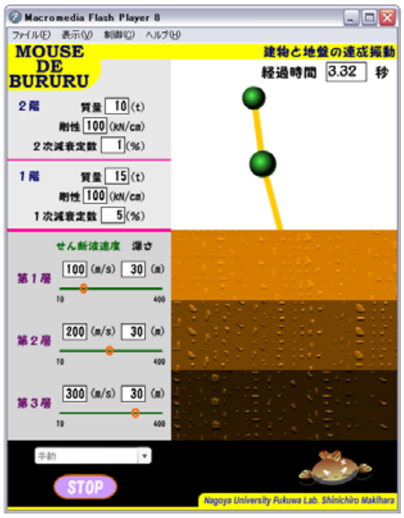
Development of public awareness by the use of experimental models has limits in terms of the number of participants, time, and place. To cope with this, we developed an Internet-based simulator system that has no such limits. This system complements the above-described materials for vibration experiments and consists of a virtual vibration experiment simulator using FLASH, where the building and soil responses to seismic ground motion are simulated by the movement of the mouse. We consider using the system a supplement to university lectures on dynamics. Through use of these simulators, each student experiences the following: estimation of a soil model; the soil response to seismic ground motion; building collapse simulations; simulation the effects of falling furniture; and experiments related to building responses to seismic ground motion.

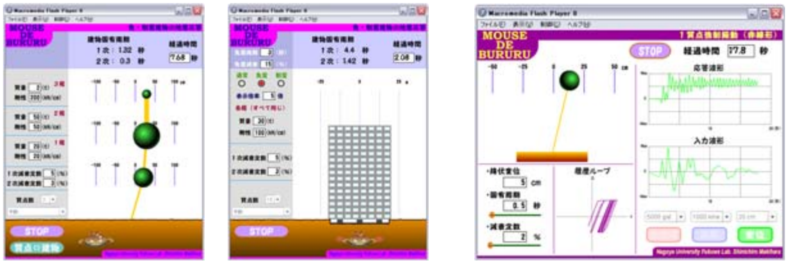
Figure 9 shows the vibration simulators using FLASH ActionScript. Some are available for use by the general public on the "BURURU" website. For example, the upper left drawing shows a response simulator for the two degrees of freedom system. If the user inputs the mass and rigidity of the first and second floors, the simulator automatically estimates the eigenvalue and the eigenmode. If the user moves the ground right and left by mouse, the building responds. Through use of this virtual experiment, the user can more readily understand the effect of the rigidity balance of the first and second floors by observing the resonance and vibration modes.

The lower left graphs shows a response simulator for multiple degrees of freedom system. Since it is easy to add the base isolation devices and dampers by clicking the button, the user can easily understand the effectiveness of base isolation and vibration control. The lower central figure shows the nonlinear response simulator for one degree of freedom system and the right drawing shows the linear response simulator for the structure founded on layered soil. By observing and comprehending these graphs, the user can understand the effect of nonlinearity, soil amplification, and the resonance between soil and structure.

This simulator increases the user's understanding of earthquake responses more than formulas and graphs because, by moving the mouse, the user can see at what period buildings are prone to vibrate and how responses are amplified and damped out according to the damping constant.

(a) Linear dynamic simulator for two DOF's system





(b) Linear dynamic simulator for multi DOF's system considering base-isolation and vibration control

(c) Nonlinear dynamic simulator for one DOF system

(d) Linear dynamic simulator for soil-layers and 2 stories structure system

Figure 9 Web based education materials by dynamic simulator using FLASH ActionScript

4. CONCLUSION

In this paper, to promote university education on dynamics and residents' awareness of seismic retrofit, we have explained various educational devices and related materials consisting of various model vibration experiment materials that plainly show the importance of seismic retrofit and an online e-learning system that supplements the materials.

The experiment materials are adaptable to various purposes and target audiences. Each consists of a vibration-producing device and various building models. We have developed a wide range of vibration-producing devices from hand-rotated versions to digitally controlled devices that require use of a PC. Furthermore, we have also created an e-learning system that, via the Internet, can be used without limitations on number of students, time, or location.

At the university where I work, the number of students interested in earthquake engineering has been steadily increasing through the use of these education materials. In the community where I live, the number of earthquake-resistant houses and buildings has been steadily increasing because of the promotion of public awareness facilitated in part by the use of these materials. Recently, at home and abroad, these materials have been used during education and public awareness activities to teach a wide range of people from government leaders to kindergarten children. This all has a great effect.

In the future, it will be desirable for numerous persons to develop and share education materials for the growth of earthquake engineering and strive to help further society's understanding of the importance of seismic retrofitting.

REFFERENCES

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