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# DEVELOPMENT OF PORTABLE VIBRATION EXPERIMENT DEVICE TO SUPPORT INTUITIVE UNDERSTANDING

OSAMU TSUJIHARA[1], YUICHI NAKATANI[1], TERUMASA OKAMOTO[2], and TAKESHI YAMAMURA[3]
[1]*National Institute of Technology, Wakayama College, Gobo, Japan*
[2]*Okayama Prefectural Government, Okayama, Japan*
[3]*SCKIKAKU Co., Ltd., Tokushima, Japan*

The scale of vibration is expressed by such measures as the acceleration and seismic intensity. However, it is not realistic for those who have no experiential sense for the scale of vibration. The intuitive feel of vibration helps to foster motivation to learn such the subjects as the earthquake disaster prevention, vibration and earthquake resistance in the department of civil engineering and the architecture. This paper introduces the portable shaking experiment device which is developed as a teaching material to support the intuitive understanding of the scale of vibration such as acceleration and seismic intensity as well as Fourier spectrum. The data of vibration recorded by the accelerometers installed at the shaking table and structure model are processed immediately and the wave form, maximum acceleration, seismic intensity and Fourier spectra are shown in real time. The effectiveness of the proposed experiment device is discussed by the questionnaire survey.

*Keywords*: Education, Shaking table, Portability, Teaching material, Questionnaire.

## 1 INTRODUCTION

Shaking table tests are considered to be effective to give intuitive understandings in the subjects such as related to the earthquake disaster prevention, vibration and earthquake resistance in the department of civil engineering and the architecture. However, those systems are generally installed at higher education institutions and are mainly used for the purpose of research. The data of the vibration of the structure model on the shaking table are measured by the measuring device such as accelerometer and they are proceeded offline. It is not interested to be frequently used in the class room.

Recently, the portable shaking table has been developed which is easy to be carried to the class room. Fukuwa *et al*. (2005) developed some portable devices. Their hand-turned shaking table including some building model is commercially supplied at a low price. The motor-driven portable shaking table was also developed by Fukuwa *et al*. (2005). They support the visual understandings about the phenomena of vibration. However, the function to support the quantitative understanding is to be required, supposing that the shaking table experiment devices are used in the class such as earthquake resistance in the department of civil engineering and architecture. Okamoto *et al*. (2015) developed the portable Vibration experiment device, in which the structure model was excited by the shaking table built in the computer. The table was controlled by the hand-operated accelerometer.

In this study, a new portable shaking experiment device is developed as a teaching material to support the intuitive understanding of the scale of vibration such as acceleration and seismic intensity as well as Fourier spectrum. The shaking table is hand-operated and the vibration of the structure model as well the table are observed by the attached accelerometers. The wave form and the Fourier spectra can be seen in real time.

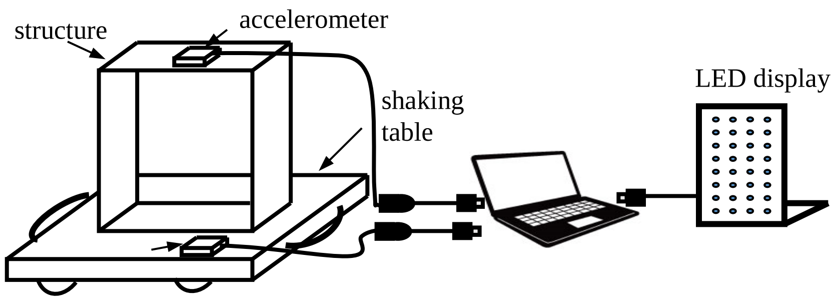


Figure 1. Hardware of experiment device.

## 2 EXPERIMENT DEVICE

### 2.1 Hardware

The hardware is composed of a shaking table, structure model, two accelerometers with serial communication interface, LED display panel and PC as shown in Figure 1. In the lesson of the theory of vibration, a system of single degree of freedom is generally used in the introduction. So that the shear deformation structure model is made by cutting an aluminum plate with thickness of 1.0 mm. The height, width and depth are 25 cm, 20 cm and six cm, respectively. The plates are joined with bolts and nuts. One accelerometer is attached on the tops of the structure model and also serves as a weight. The other accelerometer is attached on the shaking table. The shaking table is a wood board with 30 cm in width and one cm in thickness. Four rollers and two handles are attached to the underside and the sides of the board, respectively. The LED display panel is handmade as shown in Figure 2. 32 full color LEDs are attached to an aluminum plate. The panel can show the intensity of the vibration in JMA (Japan Meteorological Agency) scale as shown in Figure 3 or the comparison of maximum acceleration between the shaking table and structure model.

### 2.2 Software

The software has the following functions:

1) Data capture of the accelerometers attached to the structure model and shaking table.
2) Real time display of waveforms of the observed acceleration.
3) Display Fourier spectra and seismic intensity at the specified time interval.
4) Transmission of the maximum acceleration or seismic intensity at the specified time interval to the LED display panel.

Microsoft Visual Basic 6.0 is used for the programing. MSCOM control enables serial communication of data. The accelerometer sends acceleration of 100 samples of per second for each axis. The communication specifications are shown in Table 1.

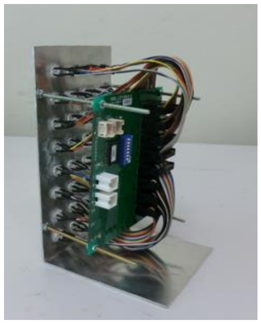

Figure 2. Back of LED display panel.

Figure 3. Sample display of JMA scale intensity.

Table 1. Communication specifications.

| | | |
|---|---|---|
| Communication method | | RS-232C |
| Transmission rate | | 19.2kbps |
| Bit configuration | Start | 1bit |
| | Data | 8bit |
| | Parity | none |
| | Stop | 1bit |

Figure 4 shows an example of a screenshot. The waveforms of acceleration and the Fourier spectra of the structure model and shaking table are shown. The waveforms are continuously updated and the Fourier spectra are recalculated at 2 seconds intervals and updated. The time interval can be selected. The sensors and components to be displayed also can be selected. In this example, X-direction components of sensors 1 (structure model) and 2 (shaking table) are selected.

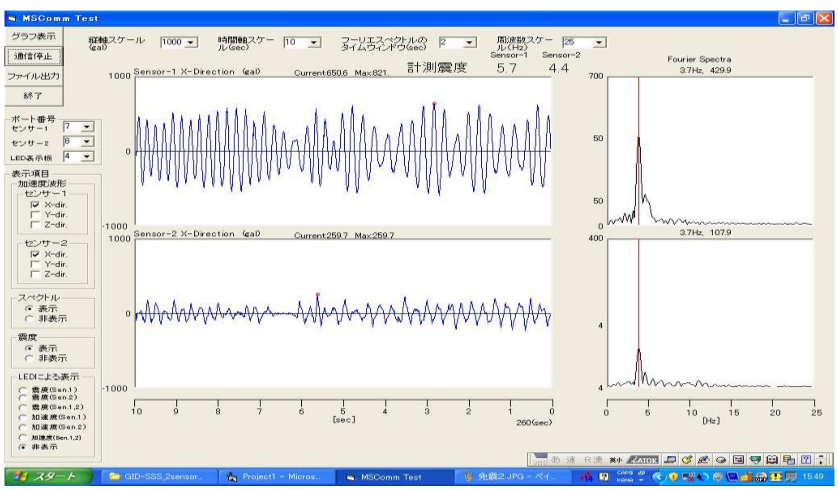


Figure 4. Example of a screenshot.

The control of LED display panel is carried out in the same program. For each LED, RGB can be designated in 16 stages, and expression of maximum of 4096 colors is possible. 32 LEDs embedded in the panel can be turned on with arbitrary timing and color. For the case of display of seismic intensity in JMA scale, the numbers of 0 to 7 are designed. The LED display panel is also used as the level bar to show the seismic intensity or the maximum acceleration at the specified time interval. With 4 LEDS in the horizontal direction as one stage, the seismic intensity or the maximum acceleration at the specified time interval can be expressed depending on the number of lit stages. By assigning each 2 columns of LEDs as the level bars of the structure model and shaking table respectively, the difference of vibration between the two can be expressed.

## 3 USE OF TEACHING MATERIALS

### 3.1 Intuitive Understanding of Scale of Vibration

The shaking table without the structure model is recommended for the intuitive understanding of the scale of vibration as shown in Figure 5. By manipulating the shaking table while watching the scale, the sense of the relationship between the strength of vibration and the scale is cultivated.

Although the explanation of difference between the maximum acceleration and seismic intensity is not easy, this teaching materials may help to cultivate the sense. Moreover, this teaching materials help the understanding of Fourier spectrum, since the difference of the spectrum depending on the manipulation of shaking table can be observed.

### 3.2 Natural Period and Damping Factor

Free vibration is the basis of the theory of vibration. The records of free vibration of the structure model can be used for the exercise in the estimation of the natural period and damping constant of the structure model. Figure 6 shows the waveform and Fourier spectrum of the acceleration of the structure model. The natural period can be estimated directly from the peak frequency of Fourier spectrum. The data of acceleration can be saved as text data. Reading the data by Microsoft Excel and drawing the waveform, the damping constant can be estimated from the ratio of two peak values of acceleration. The natural period and damping constant of this structure model were identified as 0.196 sec and 0.008, respectively.

Figure 5. Experiment using only shaking table.

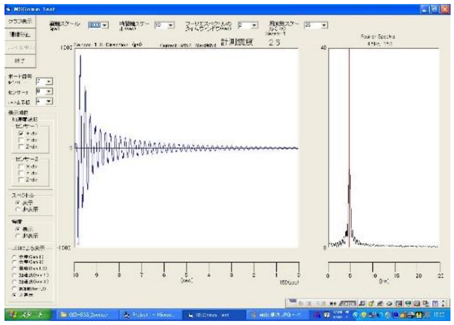

Figure 6. Screenshot of free vibration test.

### 3.3 Forced Vibration and Response of Structure Model

The structure model is excited by the shaking table. It is recognized that the structure model becomes several times the maximum acceleration or intensity depending on how the shaking table is manipulated. In addition, the shaking table is moved at a cycle close to the natural period of the structure model, the resonance can be quantitatively evaluated from the waveform and LED display panel.

The structure model can be regarded as single degree of freedom of shear deformation type. The equation of motion is shown as Eq. (1).

$$\ddot{y} + 2hn\dot{y} + n^2 y = -\ddot{\phi} \tag{1}$$

where $y, h, n, \phi$ are displacement, damping constant, natural circular frequency of structure model and displacement of shaking table, respectively. The damping constant and natural circular frequency can be estimated by the free vibration test as mentioned. The natural circular frequency is obtained from the natural period, and the data file of acceleration of shaking table is available. These data can be used for the exercise of the response analysis. Since the unknowns are acceleration, velocity and displacement of the structure model, Eq. (1) can be solved by various numerical analysis methods. It is interesting to discuss the fitness between the results of response analysis and the recorded data of acceleration of structure model as shown in Figure 7.

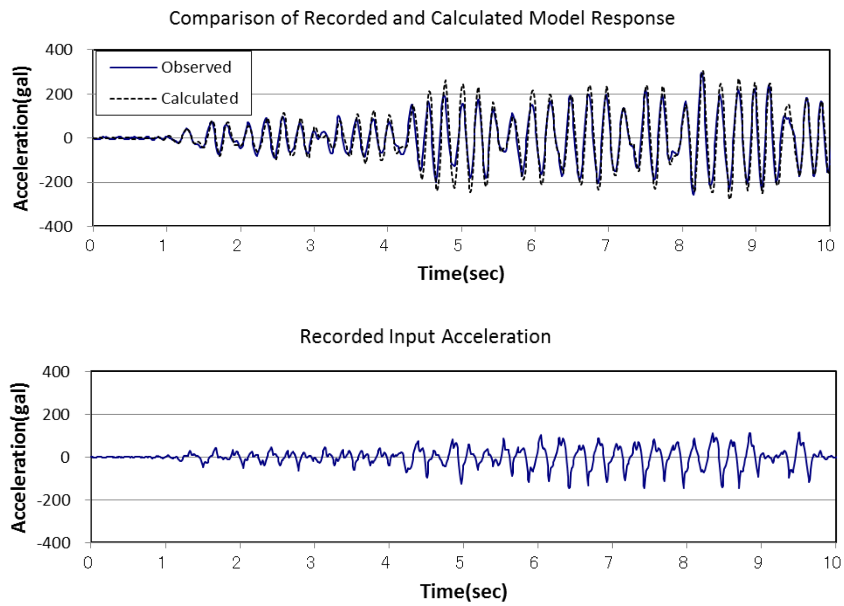


Figure 7. Comparison between analytical model responses excited by shaking table and recorded motion.

## 4 VALIDITY OF TEACHING MATERIALS

Questionnaire survey about the lessons of “Vibration Engineering” was carried out for 34 students in the fourth grade of Environmental Urban Engineering Department. Eight students answered that it had been difficult to understand. Table 2 shows the answers to the questions about the reasons why the lessons were difficult for eight students. Any two answers out of three in Table 2 could be selected. From these results, it is recognized that it is important to understand the relation between vibration phenomenon and formula and to have sense of acceleration and seismic intensity.

Next, six students in the fifth grade of Environmental Urban Engineering Department, who had taken the lessons of “Vibration Engineering”, used the teaching materials. Focusing mainly on the intuitive understanding of vibration scale, the questionnaire survey was conducted. The questions and answers are shown in Table 3. The students are to select the number of one to five to each question after the lessons by manipulating the teaching materials themselves, with one as the most negative answer and five as the most positive answer. The average values of the answers are listed in the table. All answers were more than four of five stages. Especially, intuitive understanding of the scale of acceleration and seismic intensity gained high points.

Although there are no statistical values because of the small number of subjects, a high evaluation was gained as a whole, and a certain evaluation on the effectiveness of the teaching materials was obtained. Meanwhile, the evaluation was lowered in order of the items that took time to explain. It turned out that there was room for improvement in teaching with this shaking table.

Table 2. Reasons why the lessons of "Vibration Engineering" is difficult to understand.

| Answers | Selected number |
|---|---|
| There are many formulas which are difficult to understand. | 6 |
| It is difficult to understand the relation between the phenomenon of vibration and formulas. | 6 |
| The lack of sense for the acceleration and seismic intensity reduce the interest to the lessons. | 3 |

Table 3. Results questionnaire survey for the students who tried the proposed teaching materials.

| Questions | Average value |
|---|---|
| Was this teaching materials helpful for your intuitive understanding of scale of acceleration? | 4.8 |
| Was this teaching materials helpful for your intuitive understanding of seismic intensity? | 4.5 |
| Was this teaching materials helpful for your intuitive understanding of Fourier spectrum? | 4.0 |

## 5 CONCLUSIONS

In this research, a portable vibration experiment device is developed. The feature of this device is that the user can manipulate the shaking table by himself while watching the vibration characteristics such as the waveforms, intensity, maximum acceleration and Fourier spectra in real time. It helps to cultivate the intuitive understanding of the index of vibration strength by earthquakes such as acceleration and seismic intensity, and to make students interested in lesson related to vibration engineering. High evaluation was obtained from most students who used the proposed device.

According to the questionnaire survey, it is important to understand the relation between vibration phenomenon and formulas. The proposed device helps the explanation and can provide data for exercises such as estimation of natural period and damping constant from the free vibration test of structure model and calculation of the model response excited by the shaking table.

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