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EXPERIMENT SYSTEM BY VIRTUAL SHAKING TABLE USING ACCELEROMETER

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This paper introduces an experiment system developed as a teaching material to support the lessons related to vibration and earthquake resistance in the fields of civil engineering and architecture. The hardware was composed of an accelerometer, a serial communication interface, an RS232-USB conversion adapter, and a computer. The virtual shaking table in a computer display was controlled by the hand-operated accelerometer. The response of the structure model with multi-degrees of freedom on the shaking table was calculated in real time. The findings were that hands-on experience in controlling the shaking table helps an instinctive understanding of vibration, especially acceleration and seismic intensity. A structure model with different dynamic characteristics can be built easily, so that the effect of properties, such as the natural period and damping constant on the structural motions, can be visualized, helping the understanding of the theory of vibration.

Keywords: Vibration, Teaching material, Earthquake resistance, Instinctive understanding.

1 INTRODUCTION

The indexes such as the seismic intensity and acceleration are used to explain the scale of earthquake motions and structural vibration. However, it is not easy to teach an instinctive understanding to students who have no sense about the theories of vibration. The shaking table test is one of the teaching materials, with shaking table test systems installed at higher education research institutions. The data of the vibration of the structure model on the shaking table are measured by accelerometers etc., and they are often not used in classes related to the vibration engineering.

Recently, portable shaking tables, both hand-cranked and motor-driven, have been developed for classroom use with building models by Fukuwa et al. (2005), commercially available at a low price. They support a visual understanding about the phenomena of vibration. However, support for quantitative understanding is required, assuming that the devices are used in classes such as earthquake resistance in civil engineering and architecture departments. Tsujihara et al. (2014) developed a portable shaking table device that enabled real-time measurement of motions and the calculation of their seismic intensity and Fourier spectra. The values of seismic intensity and the graphs of waveform and Fourier spectra can be visualized in real time.

In this study, a new experiment system is developed as a portable teaching material where the virtual shaking table in the computer display is controlled by a hand-operated accelerometer. Structure models can be built on the shaking table in the computer. The influence of the model parameters such as the stiffness and damping to the response can be observed.

2 VIRTUAL SHAKING TABLE SYSTEM

2.1 Hardware

The hardware is composed of a triaxial accelerometer, a serial communication interface, an RS232-USB conversion adapter, and a computer as shown in Figure 1. GID-SSS and GIS-SSS/IF232 produced by Mathematical Assist Design Laboratory are used as the accelerometer and serial communication interface, respectively. A RS232-USB conversion adapter is attached as the accessory. The cost of these devices is under 500 US dollars. Figure 2 shows the picture of the shaking table system. Figure 3 shows the accelerometer. Figure 4 shows the base with roller bearing on which the accelerometer is to be attached. The accelerometer with the base is operated from front to back and from side to side on the desk or table. The virtual shaking table in the computer display moves according to the motions of the hand-operated accelerometer.

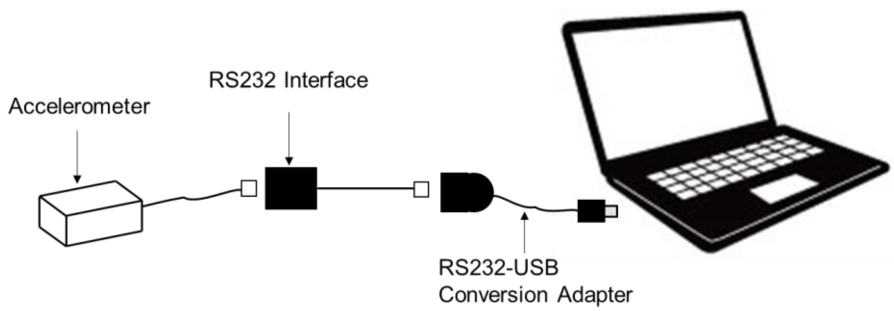

Figure 1. Hardware construction.

Figure 2. Virtual shaking table test system.

2.2 Software

2.2.1 Acquisition of data

100 measurements of acceleration per second per axis are carried out and they are sent to the computer from the

Figure 3. Accelerometer.

Figure 4. Base of accelerometer.

accelerometer. The communication specification is shown in Table 1. The receive format of data is "xxxx, yyyy, zzzz, m [CR]" in decimal characters. Abbreviations "xxxx", "yyyy" and "zzzz" denote acceleration in the direction of x, y, and z-axis, respectively. The actual values of acceleration are obtained by the correction using offset value and correction factor. Symbols "m" and "[CR]" denote the time stamp and the carriage return, respectively. Microsoft MSComm control is used as the communication tool.

Table 1. Communication specification.

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

2.2.2 Conversion of acceleration to displacement

The earthquake motions are generally measured by accelerometer. The acceleration obtained by the above-mentioned method is required to be converted to the displacement, because the motions of the virtual structure and shaking table constructed in the computer should be visualized. The time series of displacement can be calculated by two times the integration of the acceleration. However, since the noise contained in the acceleration records has an effect on the calculated displacement, a filtering process is required. The digital filter used in this study is mentioned below. The filtering should be done in real time. First the calibration of obtained acceleration data is carried out using Eq.(1).

$$a_k = a'_k - \frac{\sum_{i=1}^{n} a'_{k-i}}{n} \tag{1}$$

where a'_k and a_k are the original and corrected acceleration at the time t_k, respectively. n denotes the number of acceleration data which are to be used in the correction. If n is too small, noise from long-period components cannot be eliminated. $n = 100$ is adopted in this study for the necessity of real time processing. In this case, the components of noise up to the period of 1 second can be eliminated. The velocity

v and displacement d at the time t_{k+1} can be calculated in Eq. (2) and (3), respectively.

$$v_{k+1} = v_k + \frac{1}{2}(a_k + a_{k+1})\Delta t \tag{2}$$

$$d_{k+1} = d_k + v_k \Delta t + \frac{1}{3}\left(a_k + \frac{1}{2} a_{k+1}\right)\Delta t^2 \tag{3}$$

Figure 5 shows the example of the waveform of the acceleration before the digital filter is applied. The data were recorded at Shiogama (MYG012), Japan by K-NET during the 2011 Great East Japan Earthquake. Figures 6 and 7 show the waveforms of displacement calculated with and without filtering, respectively.

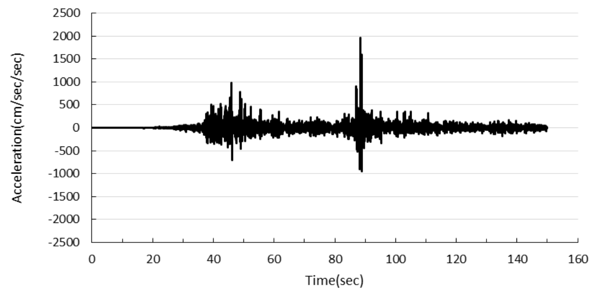

Figure 5. Original acceleration data.

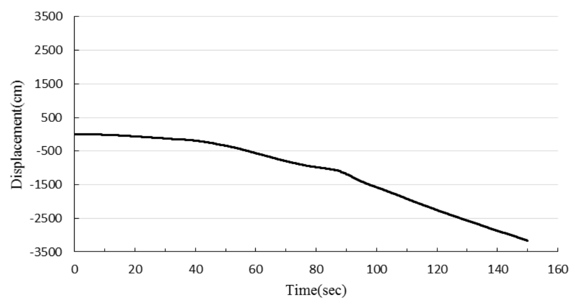

Figure 6. Displacement without filtering.

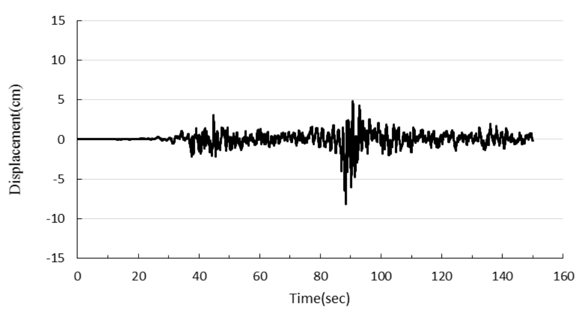

Figure 7. Displacement with filtering.

2.2.3 Response analysis

The shear-type lumped mass model is used as the structure model. The modal analysis is applied to calculate the response of the structure model with multi-degree of freedom in real time. The natural period and damping constant of each mode can be given by users. The response in the horizontal two directions can be calculated. Fourier Spectra and seismic intensity in JMA (Japan meteorological agency) scale for every assigned time window are also calculated.

2.3 Major Function

Figure 8 shows an example of the screen display in this system. The major function and its effect in this system is as follows:

1) Waveform, Fourier spectra, and seismic intensity

   The waveform of the acceleration, velocity, or displacement of shaking table and structure model can be shown with the Fourier spectra and seismic intensity in real time. They help with an instinctive understanding about the difference

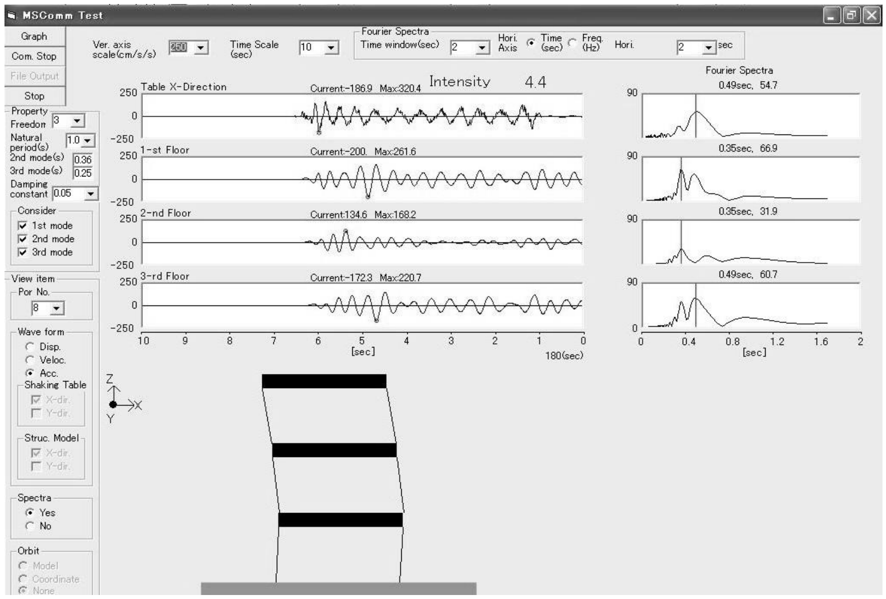

Figure 8. Screen display.

between large acceleration and large intensity. The frequency properties can be realized by the Fourier spectra, which change according to the motions of the hand-operated accelerometer.

2) Behavior

The behavior of structure model and shaking table is shown in real time on the computer display. The deformation and resonance in the motions of the structure can be observed as well as the effect of the damping constant to the motions of the structure.

3) Storing Data

The data of acceleration of input motions and the response of structure model can be stored in the disk. They can be used in the exercise to verify the theory of vibration.

3 EDUCATIONAL EFFECT

A survey was carried out to evaluate the effectiveness of the proposed experiment system. The examinees were the 38 students in the class on Vibration Engineering in the senior year of National Institute of Technology, Wakayama College. The questions were how much the experiment system was useful to understand the following items:

a. motions of large acceleration
b. difference between motions of large acceleration and large intensity
c. natural frequency
d. free vibration

e. damping constant
f. relation between damping constant and free vibration
g. forced vibration
h. resonance
i. Fourier spectrum
j. Mode in the multi-degree of freedom

The examinees were required to answer on a scale of one to five, namely from "not useful at all" to "very useful", accordingly. The levels of the system's usefulness is over 4 in almost all items except one. Items related to the acceleration and intensity, which require sensory comprehension, got high marks. The average values are 4.7 and 4.6 in questions a and b, respectively. However, a little improvement seems to be required, especially in the explanation related to Fourier spectrum.

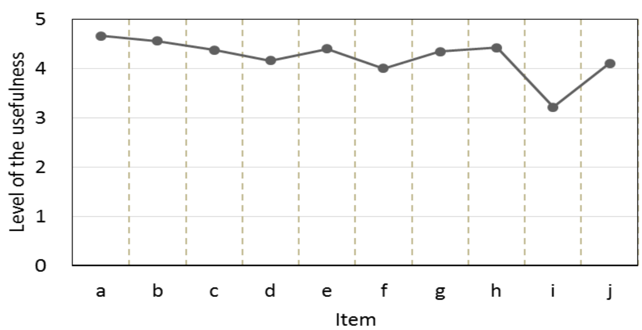

Figure 9. Results of questionnaire survey.

4 CONCLUSIONS

1) Hands-on experience of controlling a shaking table helps instinctive understanding on vibration, especially acceleration and seismic intensity.
2) The structure model with different dynamic characteristics can be built easily, so that the effect of properties, such as the natural period and damping constant on the structural motions, are visualized. It helps the understanding of the theory of vibration.

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