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ISOLATION PERFORMANCE OF INTELLIGENT SEISMIC ISOLATION SYSTEM USING AIR BEARING

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ABSTRACT

This paper describes three-dimensional isolation performance of seismic isolation system using air bearings.

Long period seismic waves having predominant period of from a few seconds to a few ten seconds have recently been observed in various earthquakes. Also resonances of high-rise buildings and sloshing of petroleum tanks in consequence of long period seismic waves have been reported. Therefore the isolation systems having very long natural period or no natural period are required.

In a previous paper [1], we proposed an isolation system having no natural period by using air bearings. Additionally we have already reported an introduction of the system, and have investigated horizontal motion during earthquake in the previous paper. It was confirmed by horizontal vibration experiment and simulation in the previous paper that the proposed system had good performance of isolation. However vertical motion should be investigated, because vertical motion varies horizontal frictional force. Therefore this paper describes investigation regarding vertical motion of the proposed system by experiment. At first, a vertical excitation test of the system is carried out so as to investigate vertical dynamic property. Then a three-dimensional vibration test using seismic waves is carried out so as to investigate performance of isolation against three-dimensional seismic waves.

INTRODUCTION

General expectations regarding seismic isolation technology have been increasing after the great Hanshin-Awaji earthquake (1995), because no isolation structure is damaged in the earthquake. As a result, several thousand isolation structures have already been built in Japan.

Earthquake Early Warning (EEW) was also developed in Japan after great Hanshin-Awaji earthquake. The EEW is a system that can expect earthquake intensity and arrival time before principal motion arrives. At first, seismographs that set up near earthquake center detect primary wave, and transmit it to Japan Meteorological Agency. Then earthquake intensity and arrival time at particular place is analyzed by using information from seismographs. Finally EEW is transmitted to medical institutions, transportation facilities, news medias, and residence in order to avoid secondary disaster.

On the other hand, concern for long period seismic waves that have predominant period of more than a few seconds has been increasing. For example, a sloshing phenomenon of petroleum tanks in the Tokachi-oki earthquake (2003) was caused by the long period seismic wave. Moreover long period seismic waves spread to Tokyo in Mid Niigata prefecture earthquake (2004), and the wave caused resonance of high-rise buildings. Therefore resonances of isolation structures by long period seismic waves are worried as well as petroleum tanks and high-rise buildings. Additionally metropolises of Japan such as Tokyo, Osaka and Nagoya, are located on sedimentary layers, and it is expected that long period seismic waves are excited in large earthquakes. However long period seismic waves require time to spread, so that early action against the seismic waves is able to prevent damage.

This study proposes intelligent seismic isolation system against above-mentioned issue. The isolation system consists of air bearings as isolation device, and the EEW as the trigger of isolation. We have already reported an introduction of the system, and have investigated horizontal motion during earthquake in a previous paper [1]. It was confirmed by horizontal vibration experiment and simulation in the previous paper that the proposed system had good performance of isolation against horizontal seismic waves. However vertical motion should be investigated, because vertical motion varies horizontal frictional force. Therefore this paper describes investigations regarding vertical motion of the proposed system by experiment.

INTELLIGENT SEISMIC ISOLATION SYSTEM USING AIR BEARING

Concept of the Isolation System

The isolation system consists of isolation device using air bearings, and isolation activation judgment device using the EEW. The strategy of this isolation system is to isolate earthquake waves by floating on a flat surface. The isolation objects are mechanical structure, computer server, floor, and detached house, considering capacity of air bearing.

Figure 1 shows the schematic of the isolation system. The system contains air bearings for floating the structure, an air compressor for providing compressed air, an air tank for accumulating compressed air, a computer for analyzing information from the EEW and judging activation of system, the EEW terminal and P-wave sensor as seismograph, and Uninterruptible Power Supply (UPS) system for supplying electric power to the computer and air compressor in case of blackout.

This system has very good performance of isolation, because the isolated structure slides on low friction surface generated by thin air film. If the structure had not floated before principal motion arrives, the structure isolates seismic wave by a slide of steel plate installed under air bearings. In other words, the air bearings become friction isolator.

Air Bearing

Air bearings are utilized as isolation device. The air bearing is one of hydrostatic bearing that can reduce contact friction between floor and the bearing by thin air film produced by compressed air. In this study, a diaphragm type air bearing is adopted as isolation device. Figure 2 and Table 1 show the mechanics of the diaphragm type air bearing and property of the bearing, respectively. The diaphragm type air bearing floats by blowing compressed air off from small holes in doughnut shape

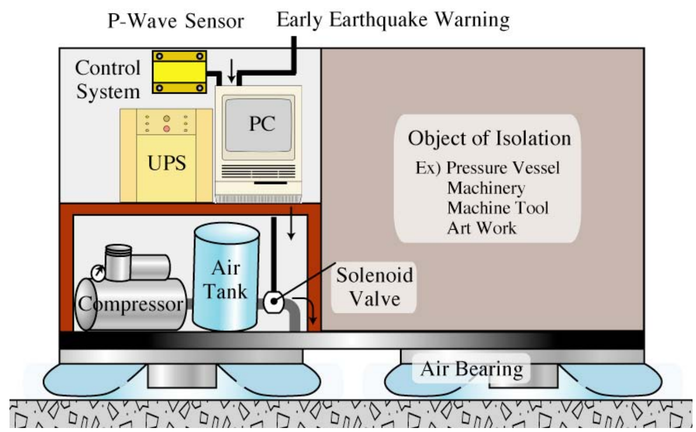


Fig. 1 Schematic of the intelligent isolation system

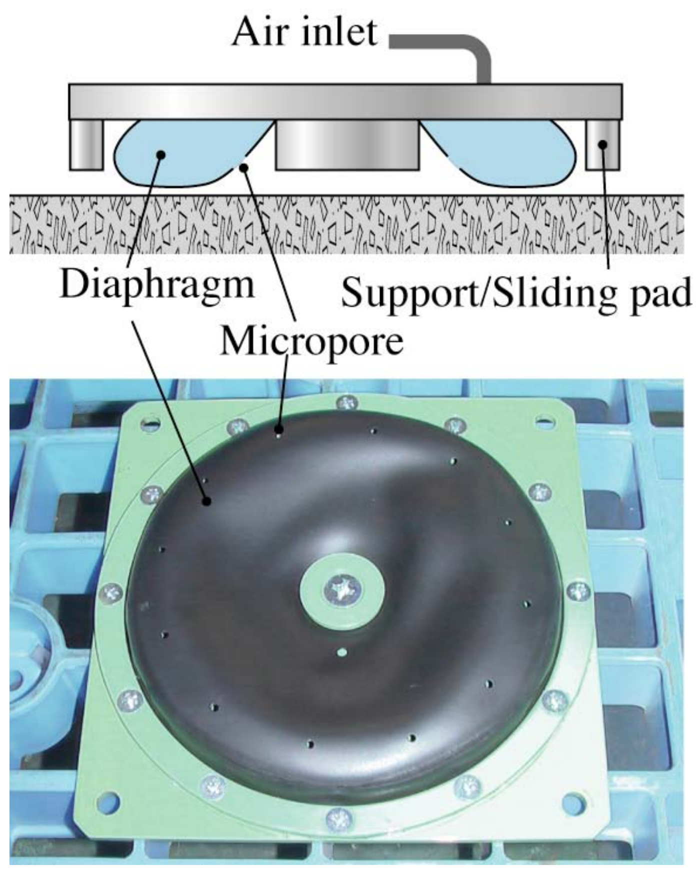


Fig. 2 Diaphragm type air bearing

Table 1 Property of diaphragm type air bearing

Capacity	～40 000[kg]
Dimension	ϕ 150～1400 [mm]
Friction coefficient	1/1000

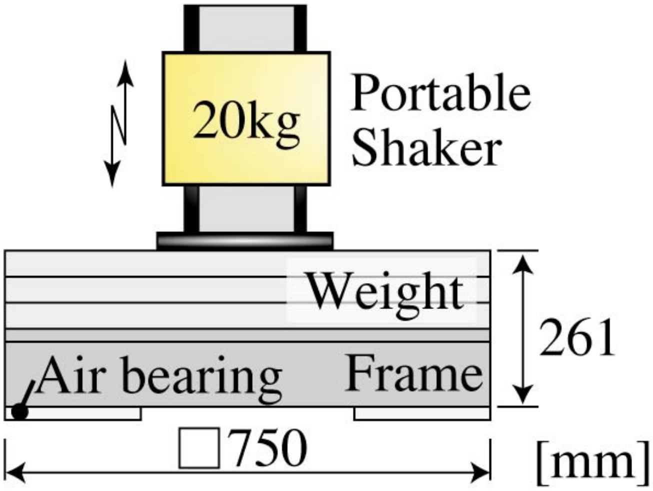


Fig. 3 Experimental model

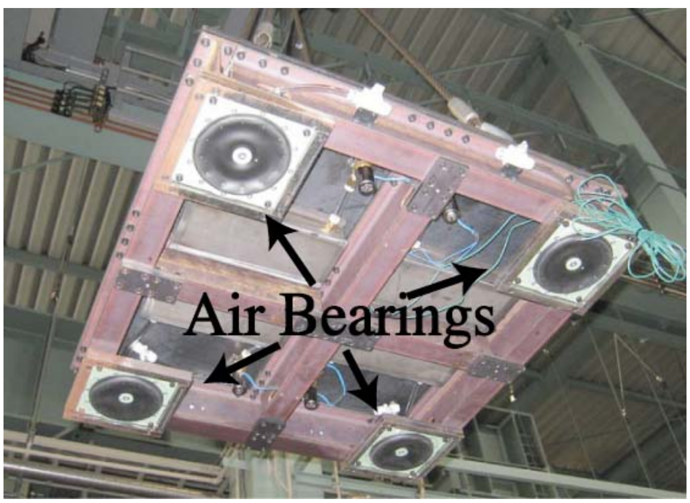


Fig. 4 Bottom view of experimental model

diaphragm made of rubber. The principle of operation is similar to air-cushion vehicle. This air bearing is generally used as heavy machinery moving equipment. The diaphragm type air bearing is available for rough surface such as concrete, because it is made of rubber and has sufficient floating height. In addition, the maximum capacity of an air bearing is 40000 kg. Therefore the diaphragm type air bearing is utilized for relatively large structure such as floors, detached houses, and low-rise buildings.

VERTICAL EXCITATION TEST

In this chapter, a vertical excitation test is examined in order to investigate vertical dynamic property. A portable shaker is applied to this experiment.

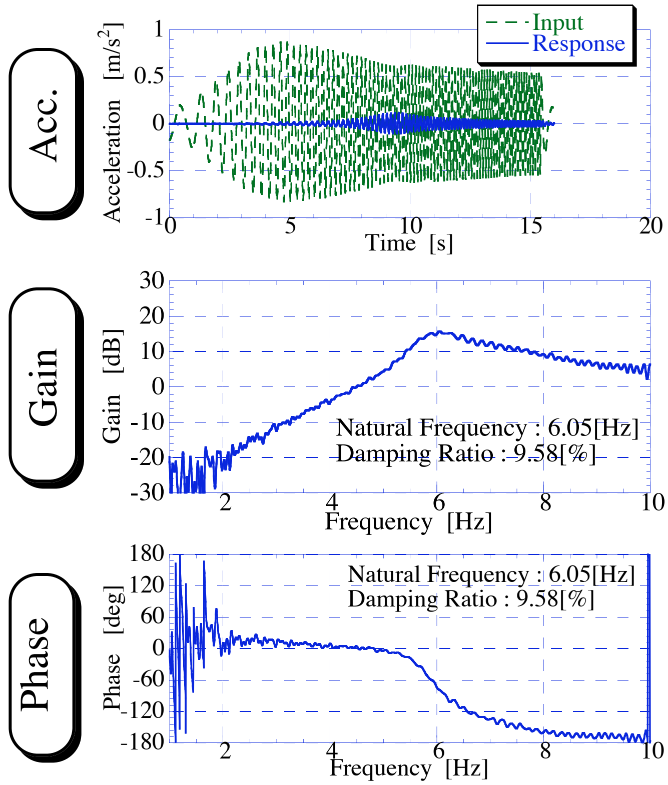


Fig. 5 Frequency response

Experimental Model

Figure 3 shows an experimental model. The experimental model is made of carbon steel and consists of a frame and weights. The frame has width of 0.750 m on a side, height of 0.141 m, and weighs 126 kg. The weight has width of 0.750 m on a side, height of 0.040 m, and weighs 170 kg. Three weights are used through out the experiment, and total weight including the frame is 636 kg. Four air bearings are installed under each corner of the frame as shown in Fig. 4. Each air bearing has capacity of 235 kg, diameter of 0.15 m. Moreover each air bearing requires 0.15 MPa of air pressure and 0.12 m^3/min of airflow. In this experiment, compressed air is supplied through air piping in an experimental facility.

Experimental Procedure

Vertical dynamic property is investigated by the portable shaker on the experimental model as shown in Fig. 3. Weight of the shaker is 46.8 kg, and weight of shaking part is 20.0 kg. Wave of excitation of the shaker is sweep wave having frequency range of 1 to 10 Hz, and the duration time is 16 seconds. Response acceleration of the experimental model and shaking part is measured. After the excitation, natural frequency and damping ratio are calculated by a transfer function from input force to response force.

Experimental Results

Figure 5 shows time history and frequency response. It is confirmed from the graph of gain that the experimental model has vertical natural frequency of 6.05 Hz, and damping ratio of 9.58 %. That is to say, the experimental model has the natural frequency around predominant frequency of typical earthquake wave. Thus there is a possibility that the isolation system resonates during earthquake. However the air bearing has good damping performance, because of small holes of the air bearing and thin air film generated between the air bearing and floor. Therefore it is expected that this damping performance prevent resonance during earthquakes.

THREE-DIMENSIONAL VIBRATION TEST

Vibration tests using a three-dimensional shaking table are examined so as to investigate performance of isolation of the system, and influence of vertical motion on horizontal motion.

Experimental Procedure

The experimental model explained in the previous chapter is also used for this experiment. In addition, a three-dimensional electromagnetic shaking table that has width of 2 m on a side is utilized for the test. Figure 6 shows the shaking table and the experimental model. Fences are placed around the experimental model in order to limit excessive displacement, and sponges are placed inside fences in order to suppress contact shock, as shown in Fig. 6. The clearance between the experimental model and sponges is 0.250 m, and thickness of sponges is 0.050 m. Compressed air is generated by air compressor powered by diesel engine, and is supplied to air bearings through an air tank, mist separator, an air dryer and regulator to regulate air condition, as shown in Fig. 7. Additionally air pressure of each air bearing is fine-tuned by speed controllers.

In this experiment, JMA Kobe waves are used as input wave, although the amplitude is adjusted according to performance of the shaking table. Moreover horizontal accelerations (NS, EW direction) of center of top of the experimental model, vertical accelerations (UD direction) of each corner of top of the experimental model, and floating height of each corner are measured. In this chapter, vertical motion of Northeast corner illustrates vertical motion of experimental model.

Influence of Vertical Motion on Horizontal Motion

In this section, influence of vertical motion on horizontal motion is investigated by 2-dimentional vibration test.

At first, one-dimensional vibration test using JMA Kobe NS wave is conducted in order to grasp behavior against horizontal input. Figure 8 shows time histories of JMA Kobe NS wave. From Fig. 8, it is confirmed that waveform of response acceleration is almost straight. Therefore this system has adequate performance of isolation against horizontal input.

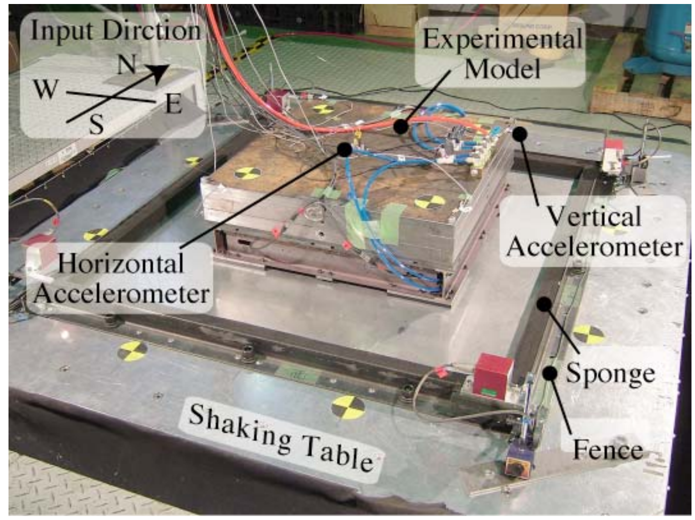


Fig. 6 Shaking table and experimental model

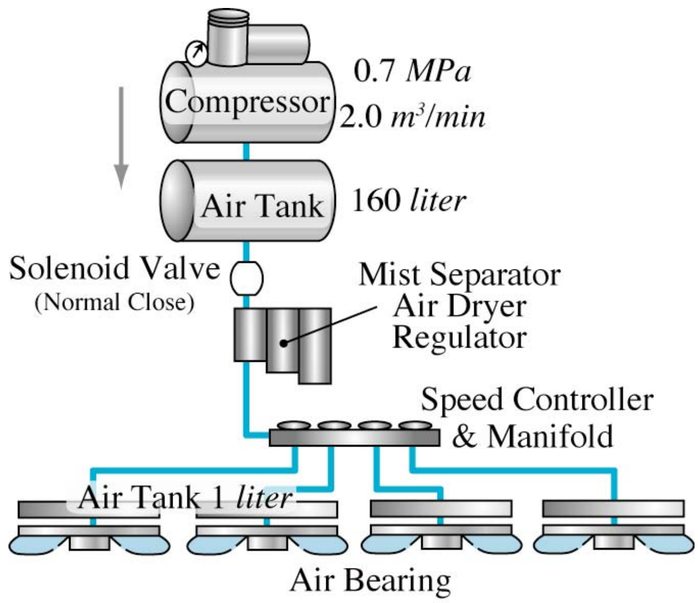


Fig. 7 Flow of air

Floating height is constant as well. Therefore the experimental model is very stable against horizontal input.

Next, one-dimensional vibration test using JMA Kobe UD wave is conducted in order to grasp behavior against vertical input. Figure 9 shows time histories of JMA Kobe UD wave. From Fig. 9, it is confirmed that vertical response acceleration is equivalent to vertical input acceleration, although the experimental model has the natural frequency around predominant frequency of input wave. This is because the experimental model has adequate vertical damping performance. Meanwhile, floating height varies according to input wave. However the variation range is small, that is 3 mm peak to peak. Therefore there are few risks of vertical collision between the experimental model and the shaking table.

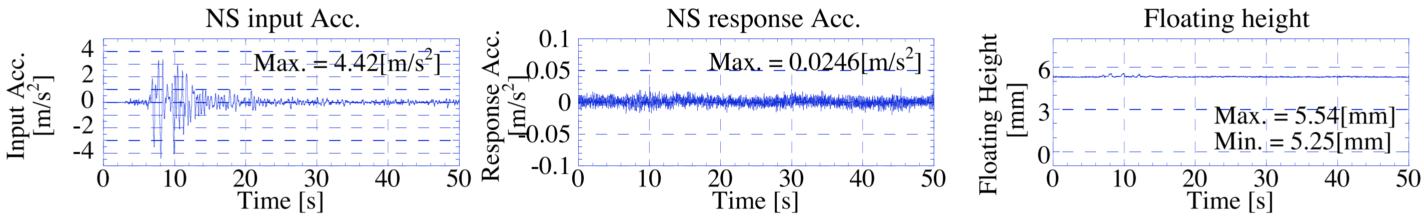


Fig. 8 Time histories (JMA Kobe NS wave 4.42[m/s^2])

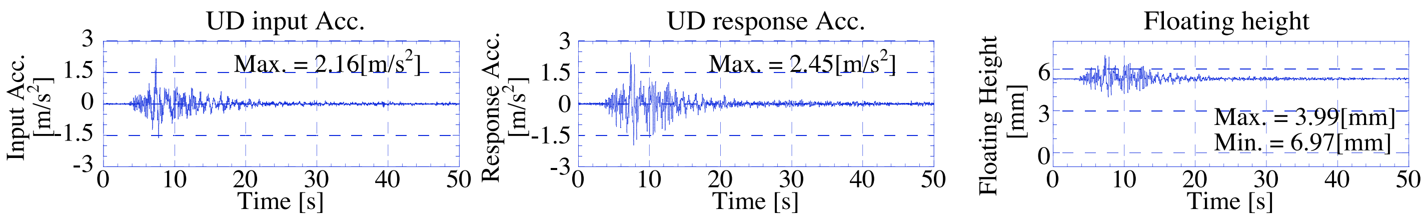


Fig. 9 Time histories (JMA Kobe UD wave 2.16[m/s^2])

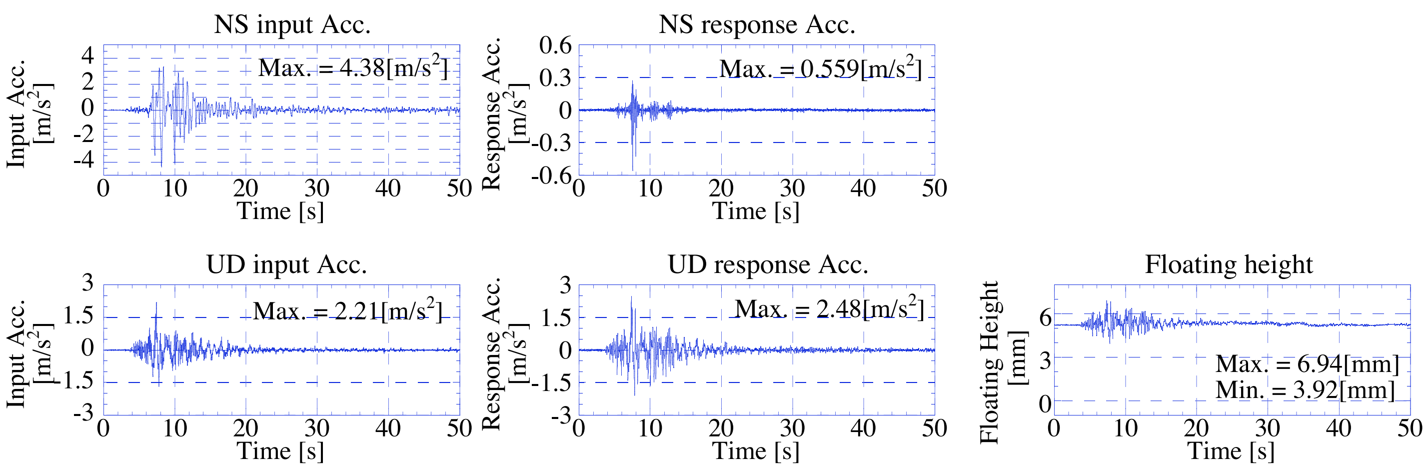
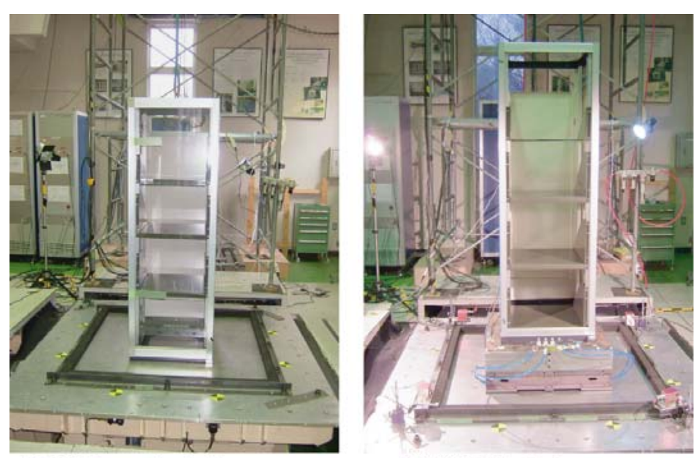


Fig. 10 Time histories (JMA Kobe NS wave 4.38[m/s^2] / UD wave 2.21[m/s^2])

Finally, JMA Kobe NS and UD waves are input at the same time in order to investigate influence of vertical motion on horizontal motion. Figure 10 shows time histories of JMA Kobe NS / UD waves. Upper graphs show horizontal motion, and lower graphs show vertical motion. From Fig. 10, it is confirmed that horizontal response acceleration is big compared with Fig. 8. This results from rocking motion caused by vertical response. However the maximum horizontal response acceleration is 12.8 % of the maximum horizontal input acceleration. Consequently the isolation system retains good isolation performance, although vertical motion affects horizontal motion. On the other hand, it is confirmed that vertical response acceleration is equivalent to Fig. 9. Therefore horizontal motion does not affect vertical motion.



(a) Without isolation system (b) With isolation system

Fig. 11 Computer server rack

Isolation Performance against 3-D Seismic Wave

In this section, isolation performance of the system against three-dimensional seismic wave is investigated by three-dimensional vibration test. A computer server rack is applied as an isolation target. The computer server rack has width of 0.565 m, depth of 0.675 m, height of 1.750 m, weight of 102 kg. Moreover it is placed on the experimental model or the shaking table without fixing, as shown in Fig. 11. Accelerations (NS, EW, UD direction) of top of the computer server rack are measured by accelerometers.

Figure 12 shows maximum acceleration as an example of experimental results. From Fig. 12, it is confirmed that responses of the computer server rack without isolation system resonate. On the other hand, isolation system suppresses horizontal response acceleration compared with input. However responses of server rack are bigger than frame. This results from rocking motion caused by vertical input. Consequently the isolation performance of proposed isolation system against three-dimensional seismic wave is confirmed.

CONCLUSION

This paper described investigations regarding vertical motion of proposed system by experiment. Results of this paper are summarized as follows.

(1) From vertical excitation test, it was confirmed that the proposed isolation system has the vertical natural frequency around predominant frequency of typical earthquake wave. However the air bearing has good damping performance. Therefore this damping performance prevents resonance during earthquakes.

(2) From vibration test, it was confirmed that vertical motion affects horizontal motion. On the other hand, horizontal motion does not affect vertical motion.

(3) From vibration test, it was confirmed that proposed isolation system has good isolation performance against three-dimensional seismic wave as well as horizontal seismic wave.

In the future, simulation and experiment containing entire process from the activation judgment to seismic isolation will be carried out.

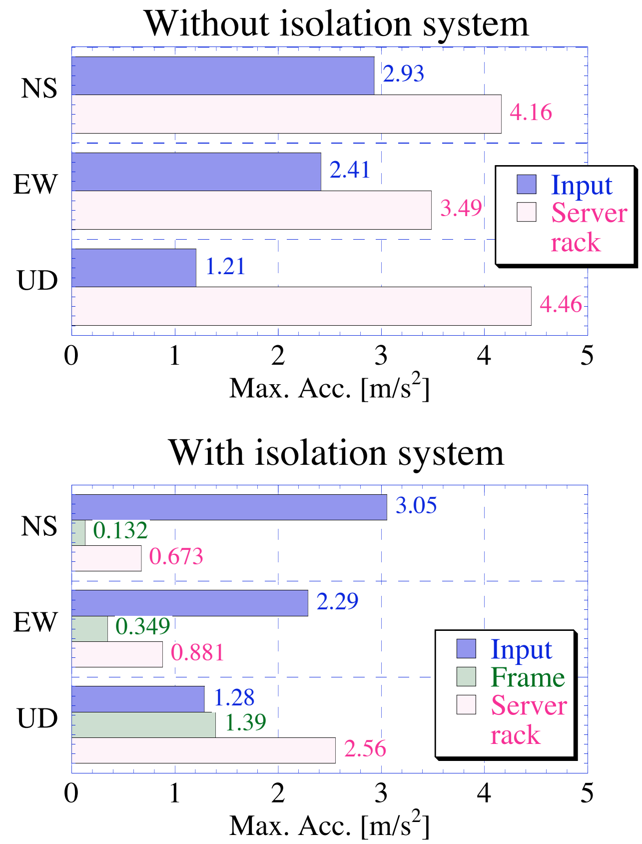


Fig. 12 Comparison of maximum response value

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