Bull. ERS, No.14 (1981)

EXPERIMENTAL TESTS OF AN EARTHQUAKE ISOLATION FLOOR FOR COMPUTER SYSTEM

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SYNOPSIS

This paper deals with experimental tests of an actual-sized model of an earthquake isolation floor which is proposed for isolating computer systems from earthquake attack. The floor is constructed on four or more isolation units with pre-tensed springs, by which it can slide smoothly when the inertia force due to earthquake exceeds the set-up force of pre-tensed springs. A series of experimental tests was carried out including sinusoidal and seismic excitation tests and both tests involved one-dimensional and horizontal two-dimensional excitations. An actual computer system was installed on the experimental model of the earthquake isolation floor for the tests. Through the series of tests, basic data on dynamic behavior of the floor were obtained and satisfactory isolation effect of the floor was demonstrated. It was also confirmed that the computer system on the floor maintained the normal function during severe seismic excitation.

INTRODUCTION

Under destructive earthquake condition, floor response accelerations amount to very large values, e.g. 1G, near the top of buildings, in particular, low or medium height ones. Therefore earthquake protection becomes important for computer systems which are often installed in the upper level of such buildings. As one of the earthquake protection measures, earthquake isolation floors, which can reduce the input accelerations to the computer systems on them by sliding on the slabs of building, recently

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attract much attention in Japan.

In this study, a new type of earthquake isolation floor is proposed. This floor is constructed on four or more isolation units. In the first phase of study, fundamental properties of the isolation unit such as vibration characteristics and performance of isolation were examined through experiments and analysis.(1)-(3) In the second phase, experimental tests of an actual-sized model, which was a part of the actual earthquake isolation floor manufactured by Mitsubishi Steel MFG. Co., Ltd., were carried out. An actual computer system was employed for the tests under the cooperation of a computer maker. In this paper, outlines and results of the experimental tests are described.

ISOLATION SYSTEM

Fundamental concept of the isolation unit used for the earthquake isolation floor is schematically shown in Fig. 1. The isolation unit consists of a moving element capable of sliding smoothly and a support structure around it, and motion of the moving element is constrained by pre-tensed springs (Fig. 1(a)) or pre-compressed springs (Fig. 1(b)). Hence, if the external force imposed on the moving element is less than the set-up force of springs, it does not move; when the inertia force imposed on the moving element during an earthquake exceeds the set-up force, it begins to slide. Thus the isolation unit has no trigger mechanism to release a lock mechanism. This leads to the reliable function of the isolation unit. Also, it is one of the merits that the moving element automatically returns to the initial state when the earthquake is over.

On the difference between the pre-tension type and the pre-compression type of the isolation unit, springs of the former are able to achieve lower stiffness and accept larger deformation than those of the latter. Then the former is usually adopted except special cases.

The earthquake isolation floor for computer system is schematically shown in Fig. 2. The isolation units are set at the corners, and other points if necessary, of a room and moving elements without springs are also set to share the dead load. All moving elements are fasten to a grid of rigid beams on which usual free-access-floor panels are set (as shown in Fig. 4). Near walls and columns, special covers are set for the clearance gap which allows the floor to move during an earthquake.

EXPERIMENTAL MODEL AND TESTING FACILITY

The isolation unit used for the actual earthquake isolation floor is shown in Fig. 3. Figures 4 show the assembly process of the unit and the floor (the experimental actual-sized model). The moving element of the isolation unit has nine steel ball bearings which support the dead weight (1960N(200Kgf)x9) and enable it to slide smoothly.

In the experimental work, the actual-sized model of the earthquake isolation floor was installed on a six meter square shaking table as shown in Figs. 5, 6, on which an actual computer system was set, and along a side of which special covers were set to simulate the situation near a wall. The computer system consisted of a central processing unit (CPU), a line printer (LP), a magnetic tape unit (MT), a disk pack unit (DISK), a card reader (CR), a console panel and a display (CONSOLE, CRT), all of which were supported by levelers on the floor. Equipment to monitor the normal function of the computer system after and/or during some excitation tests was also set beside the shaking table. In Table 1 weights of the floor and the computer system are listed.

The pre-tensed springs of the isolation unit were designed in such a way that the spring constant of each spring was 755.8N/m (0.7713Kgf/cm) and were set in such a way that the pre-tension force was 210.4N (21.47Kgf) for the experimental model. Figure 7 shows the observed restoring force and static friction force when the static displacement of the floor is given in X-direction. In Fig. 7, the solid line shows the restoring force derived from sums of stiffnesses and pre-tension forces of eight springs set in X-direction, which is a nonlinear restoring force. Then, if the springs are set without pre-tension (hence the restoring force is linear), the natural frequency of the floor will be 0.227Hz.

The experimental tests were carried out using the shaking table capable of horizontal two-dimensional excitation in Takasago Technical Institute of Mitsubishi Heavy Industries, Ltd. The main performance characteristics of the shaking table are shown in Table 2.

TEST PROGRAMME

The test programme included sinusoidal excitation tests and seismic excitation tests and both tests involved one-dimensional and (horizontal) two-dimensional excitations. The sinusoidal excitation tests were carried out to collect the basic data on dynamic behavior of the earthquake isolation floor. Since the dynamic behavior is nonlinear, resonance curves were observed for increasing frequency of sinusoidal excitation and decreasing one when the displacement amplitudes of sinusoidal excitation were kept constant and when the acceleration amplitudes were.

The seismic excitation tests were carried out to demonstrate the isolation effect of the earthquake isolation floor. Earthquake ground motion records used in the tests were (1) El Centro NS, EW (1940 Imperial Valley earthquake), (2) Hachinohe NS, EW (1968 Tokachi-oki earthquake), (3) Tohoku University NS, EW (1978 Miyagi-ken-oki earthquake); and their filtered time-histories were also used so as to simulate floor responses. The filters were a single-mass-system with a natural frequency of 2Hz and a critical damping ratio of 3%, whose responses are called "Floor responses A", and one with a natural frequency of 3Hz and a critical damping ratio of 3%, whose responses are called "Floor responses B". Due to the limits of the shaking table, the maximum accelerations of excitation were about 300 GAL for ground motions, about 700 GAL for Floor responses A and about 1G for Floor responses B.

Response accelerations at various points were measured, including accelerations in X-and Y-directions at a point on the shaking table, a representative point on the floor which was the center of four isolation units and a point on the moving element of each isolation unit, and moreover, accelerations of CPU, MT and DISK. Among them, the most important data are the accelerations measured at the representative point on the floor. The following results of excitation tests were derived from these data. Though these data give us no information on rotational motion of the floor, it is mentioned that the rotation can be neglected compared with translations in X-and Y-directions.

RESULTS OF SINUSOIDAL EXCITATION TESTS

ONE-DIMENSIONAL EXCITATION TESTS: Figures 8, 9 are resonance curves of X-direction acceleration at the representative point on the floor when the displacement amplitude, a, and the acceleration amplitude, A, of sinusoidal excitation are kept constant respectively. The tests were not carried out for Y-direction. These figures show that the response acceleration of the floor scarcely increases though the displacement or the acceleration amplitude of excitation increases, particulary, Fig. 9 shows the isolation effect clearly. Figure 8 also shows that the nonlinear properties of the floor are of soft-spring type.

TWO-DIMENSIONAL EXCITATION TESTS: Inputs of excitation used in the two-dimensional sinusoidal excitation tests were of those whose vectors made circles counterclockwise, namely, the amplitudes of X-and Y-components of each input were the same and the phase of X-component had delay of $\pi/2$ compared with that of Y-component. Figures 10, 11 are resonance curves of X-and Y-direction accelerations at the representative point on the floor when the displacement amplitudes, a_x , a_y ($a_x = a_y$), and the acceleration amplitudes, A_x , A_y ($A_x = A_y$), of sinusoidal excitation are kept constant respectively. Figures 12 show time-histories of the response accelerations when the displacement amplitudes of excitation are $a_x = a_y = 40$ mm. Figures 13 are Lissajour diagrams of the response accelerations when the acceleration amplitudes of excitation are $A_x = A_y = 500$ GAL, in which, in the case of 2.5Hz, Lissajour diagram of the input acceleration is also shown.

Figures 10, 11 and 12 show that there is little difference between X-and Y-direction responses. Comparing Figs. 11 with Fig. 9, it is found that the effect of isolation in the case of two-dimensional excitation is equivalent to or better than that in the case of one-dimensional excitation. Comparing Figs. 10 with Fig. 8, it is found that the resonance curves in the case of two-dimensional excitation scarcely show the nonlinear properties of soft-spring type such as the jumping phenomenon or the hysteresis which is observed in the resonance curve in the case of one-dimensional excitation. Figures 13 show the apparent effect of isolation.

RESULTS OF SEISMIC EXCITATION TESTS

ONE-DIMENSIONAL EXCITATION TESTS: Inputs of excitation used in the one-dimensional seismic excitation tests were, as mentioned before, six ground motions, El Centro NS, EW, Hachinohe NS, EW, Tohoku University NS, EW, six Floor Responses A which were responses of a single-mass-system with 2Hz natural frequency and 3% critical damping to those and six Floor Responses B which were responses of a single-mass-system with 3Hz natural frequency and 3% critical damping to those. The excitation tests were carried out for both X-and Y-directions.

In Fig. 14, maximum accelerations of the shaking table and the earthquake isolation floor in each case of inputs are shown by bar-graphs. Due to the limits of the shaking table, the maximum accelerations of excitation are about 300 GAL for ground motions, about 700 GAL for Floor Responses A and about 1G for Floor Responses B. To those, the maximum response accelerations of the earthquake isolation floor are 120-140 GAL in the case of ground motions and 150-170 GAL in the case of Floor Responses A, B. Thus, the isolation effect of the floor is evident.

TWO-DIMENSIONAL EXCITATION TESTS: In the two-dimensional seismic excitation tests, NS-and EW-components of three ground motions, El Centro, Hachinohe and Tohoku University, of three Floor Responses A and of three Floor Responses B were used for X-and Y-components of the inputs of excitation respectively. The maximum accelerations of X-and Y-components of each input were set in such a way that they were the same in the case of ground motions and that they were, respectively, proportional to the magnification factors of the filter for NS-and EW-components of the ground motion in the case of Floor Responses A, B.

In Fig. 15, X-and Y-maximum accelerations of the shaking table and the earthquake isolation floor in each case of inputs are shown by bar-graphs. Figures 16 are time-histories of X-and Y-accelerations of the shaking table and the earthquake isolation floor when the input is Floor Response A of Tohoku University, where the response accelerations of the floor are shown in two scales. Figures 17 are Lissajour diagrams of X-and Y-accelerations of the shaking table and the earthquake isolation floor shown in Fig. 16. The excitation condition of these tests is the most realistic one in the series of tests described here. Even under such excitation condition, the isolation effect of the floor is satisfactory as shown in Figs. 15-17.

CONCLUDING REMARKS

From results of the experimental tests of the actual-sized model, it is concluded that the proposed earthquake isolation floor has satisfactory performance of isolation and enough feasibility for actual use. At the same time, it is found the floor has some small defects to be improved; then the floor is necessary to be improved in them hereafter. It was also one of the objects of the experimental tests to confirm the normal function of the computer system during excitation, and it is concluded that the computer system on the earthquake isolation floor is able to maintain the normal function during severe seismic excitation.

ACKNOWLEDGEMENT

The authors would like to express their appreciation to Dr. K. Shiraki and the staff of Takasago Technical Institute of Mitsubishi Heavy Industries, Ltd. and engineers of the computer maker for their cooperation.

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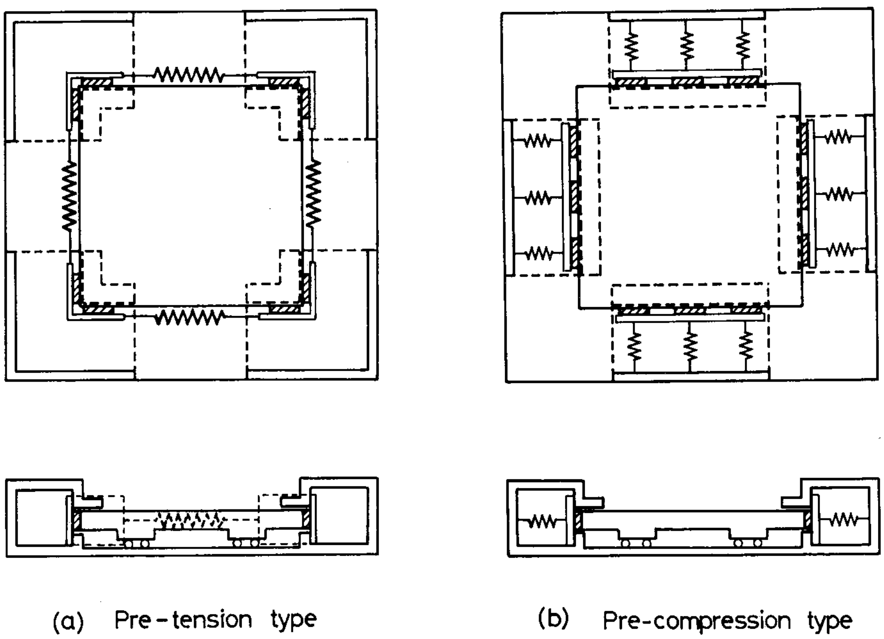


Fig. 1: Schematic drawing of two types of the isolation unit

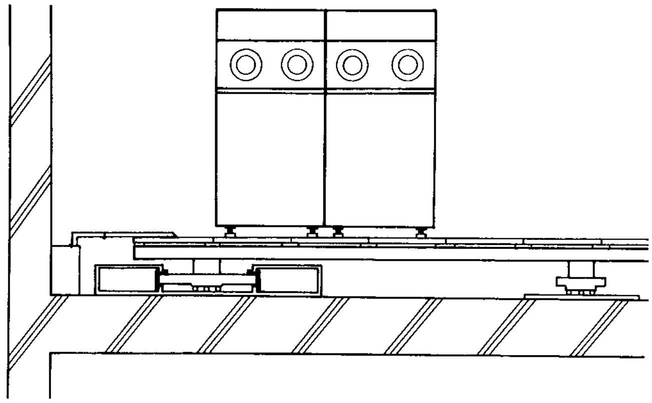


Fig. 2: Schematic drawing of the earthquake isolation floor for computer system

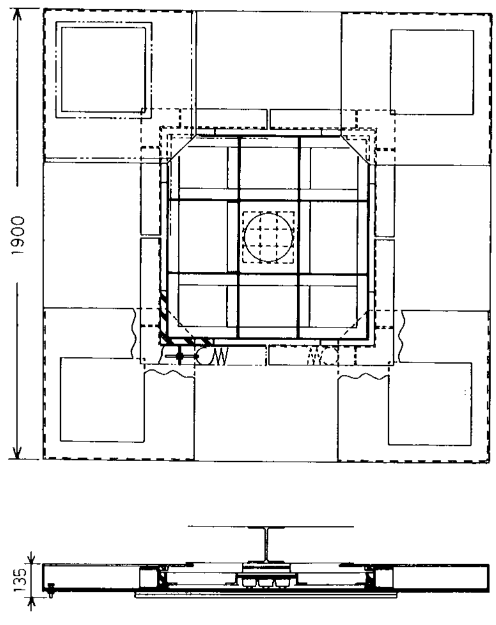
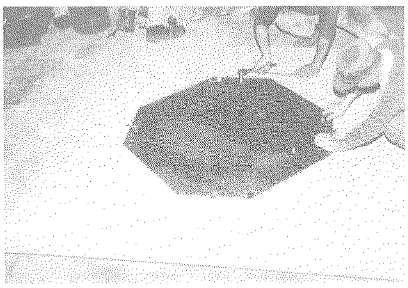
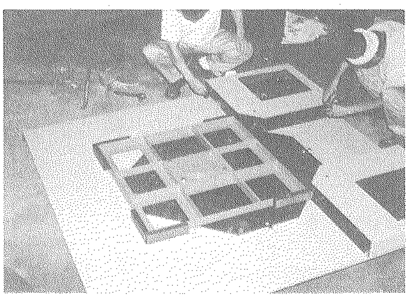


Fig. 3: Isolation unit of pre-tension type used for the actual earthquake isolation floor

(a)



(b)



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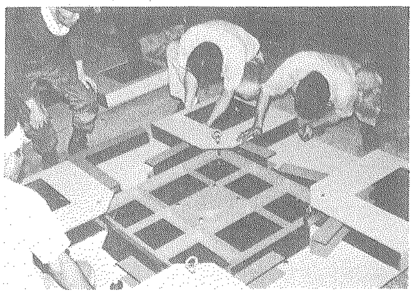

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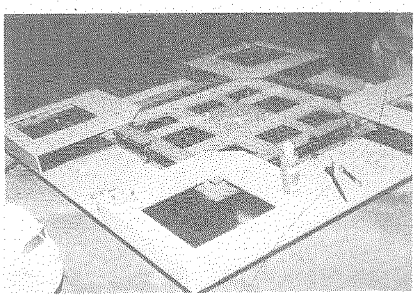

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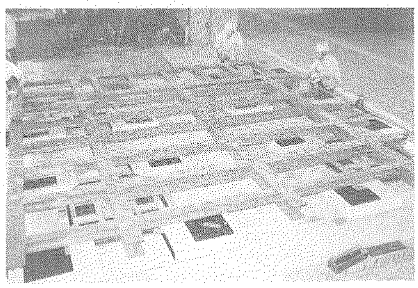

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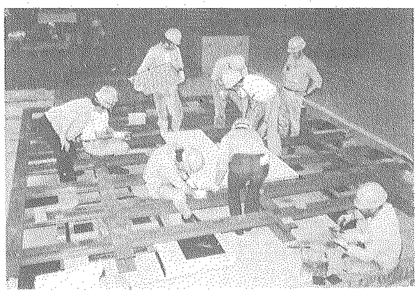

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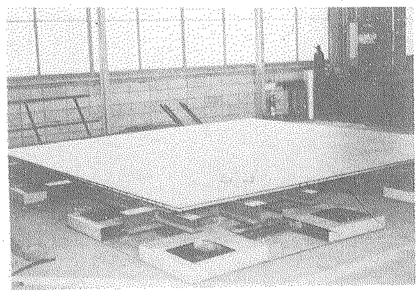

(h)

Fig. 4: Assembly process of the isolation unit and the isolation floor (the actual-sized experimental model)

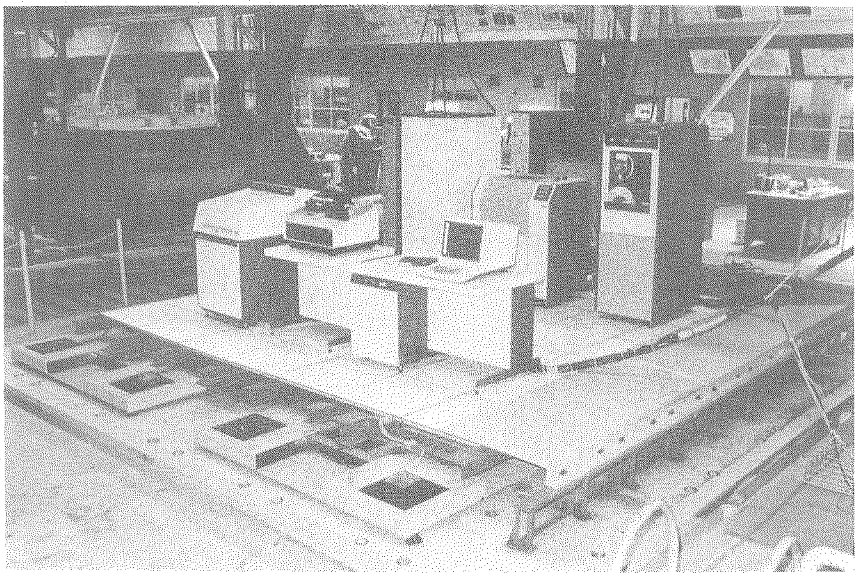

Fig. 5: Actual-sized experimental model with an actual computer system

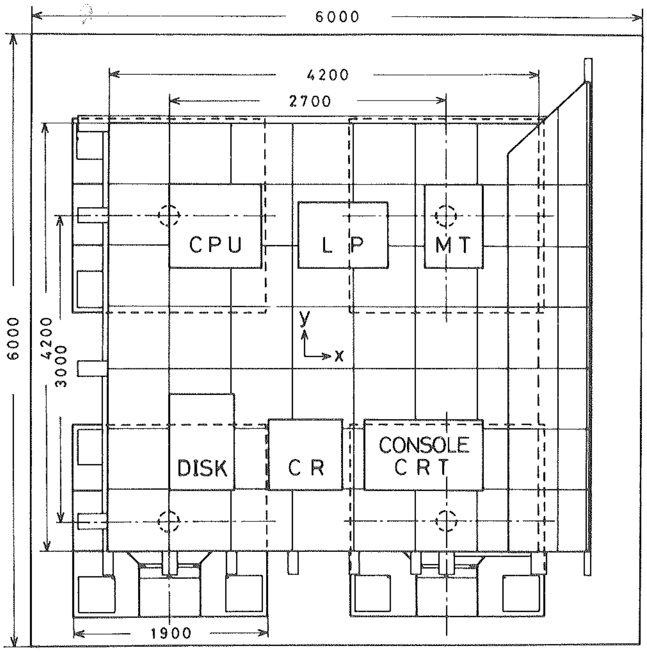

Fig. 6: Dimensions of the experimental model

Table 1: Weights of the floor and the computer system

Isolation floor (moving part)	1450 kg
Computer system	1515
CPU	370
LP	400
MT	240
DISK	280
CR	70
CONSOLE	65
CRT	40
Cords	50
Total	2965

Table 2: Main performance characteristics of the shaking table

Excitation capacity	
Horizontal two direction	50 ton·g (each)
Horizontal one direction	100 ton·g
Maximum amplitude	± 50 mm
Table size	6 m × 6 m
Maximum load	100 ton
Frequency range	0.1 Hz - 50 Hz
Shaking method	Electric, Oil-pressured servo method

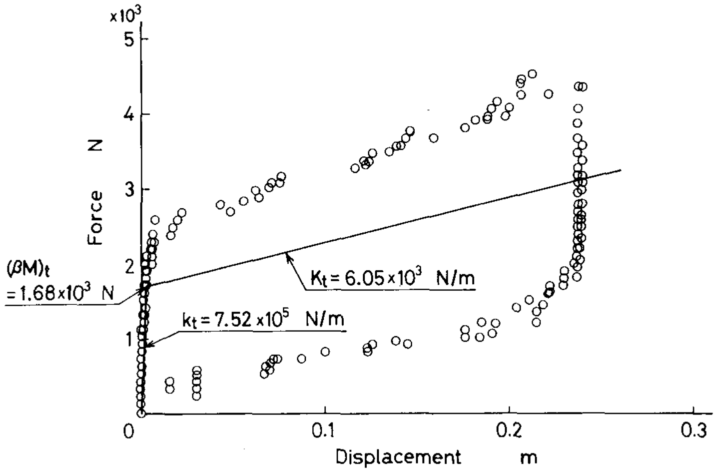

Fig. 7: Nonlinear restoring force and static friction force observed for the experimental model

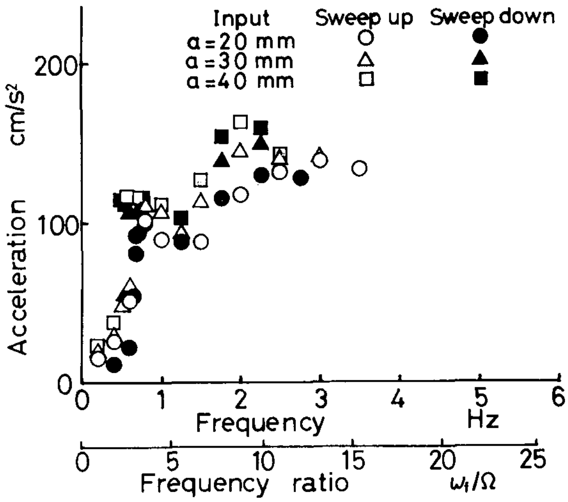

Fig. 8: Resonance curves for response acceleration of the floor to one-dimensional sinusoidal excitation in the case of displacement amplitude of excitation being constant

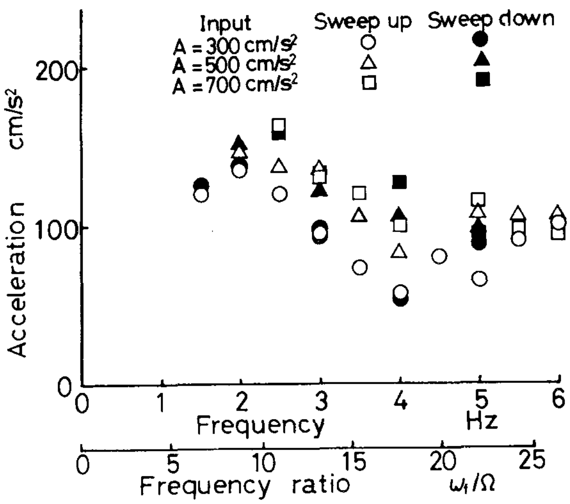

Fig. 9: Resonance curves for response acceleration of the floor to one-dimensional sinusoidal excitation in the case of acceleration amplitude of excitation being constant

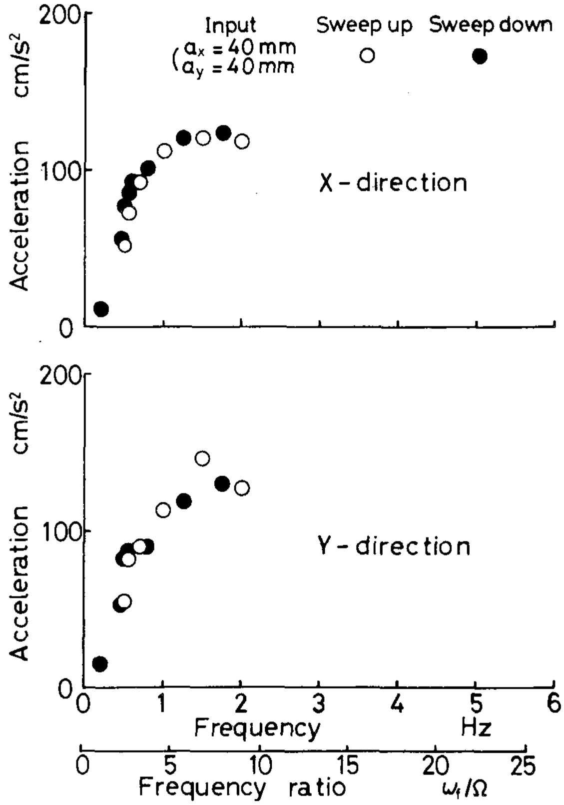

Fig. 10: Resonance curves for response accelerations of the floor to two-dimensional sinusoidal excitation in the case of displacement amplitudes of excitation being constant

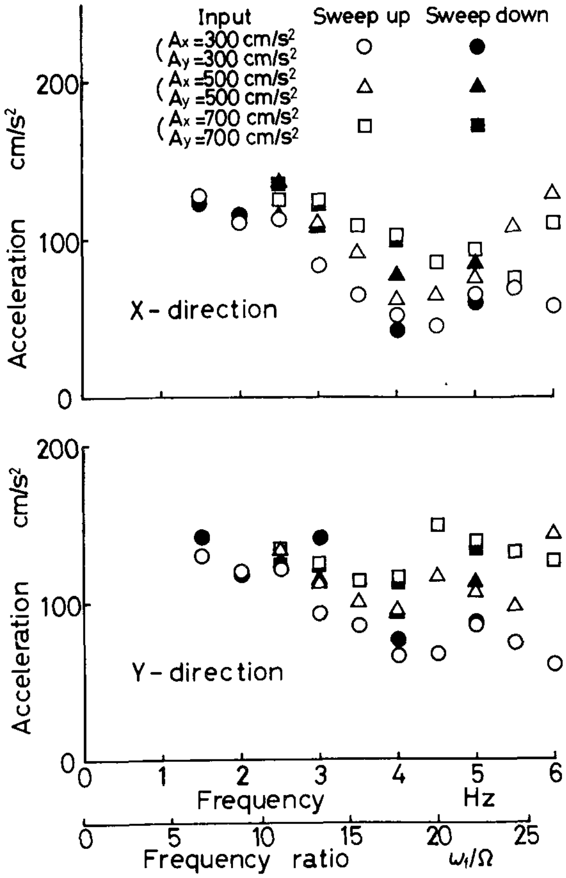

Fig. 11: Resonance curves for response accelerations of the floor to two-dimensional sinusoidal excitation in the case of acceleration amplitudes of excitation being constant

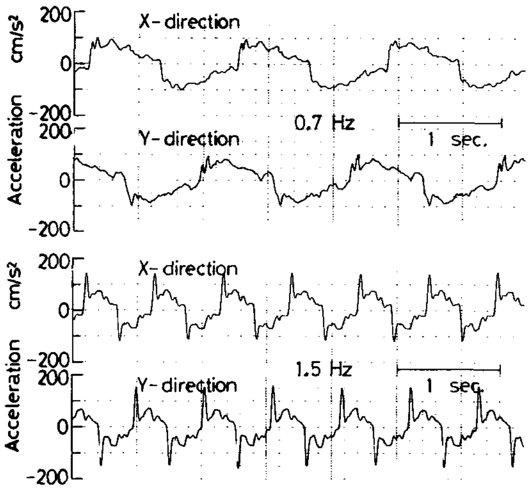

Fig. 12: Response accelerations of the floor in the case of displacement amplitudes of excitation being $a_x = a_y = 40$ mm

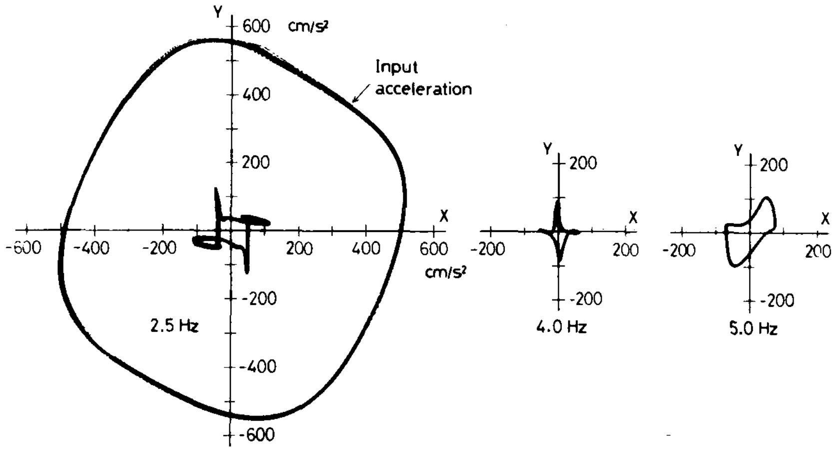

Fig. 13: Lissajour diagrams for response accelerations of the floor in the case of acceleration amplitudes of excitation being $A_x = A_y = 500$ GAL

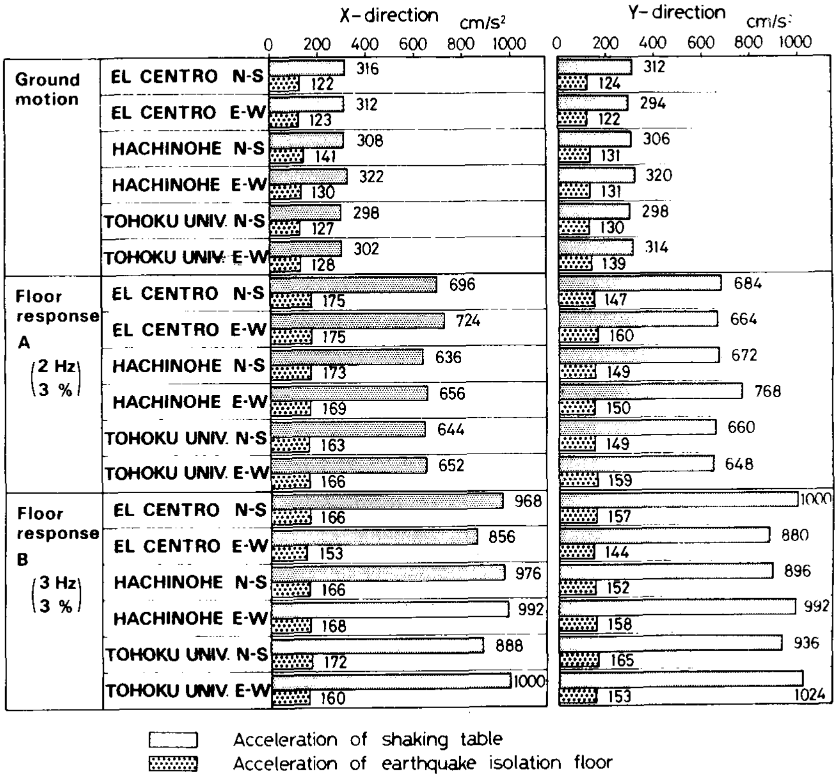

Fig. 14: Maximum accelerations of the shaking table and the earthquake isolation floor for various one-dimensional seismic excitation tests

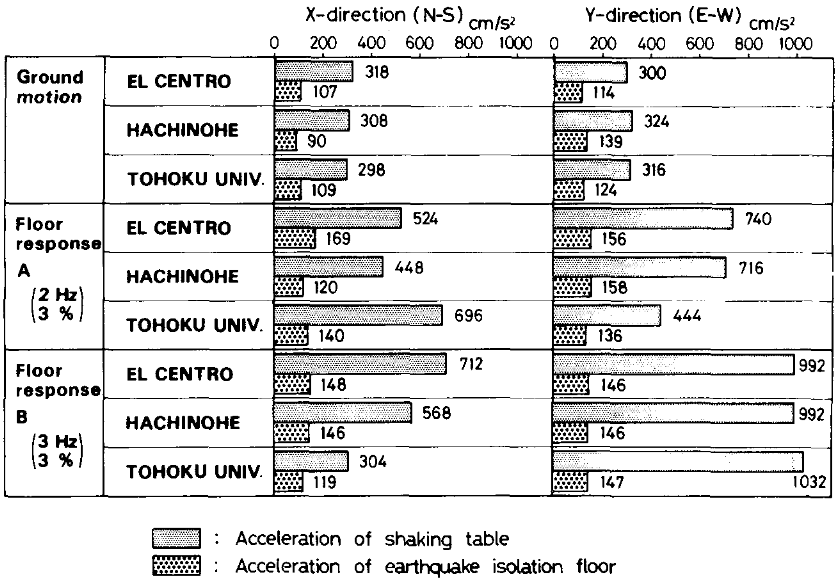

Fig. 15: Maximum accelerations of the shaking table and the earthquake isolation floor for various two-dimensional seismic excitation tests

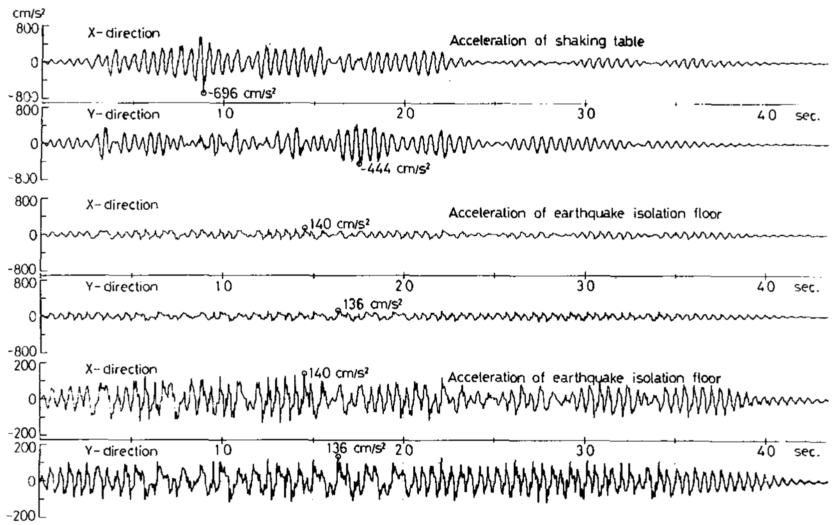

Fig. 16: Accelerations of the shaking table and the earthquake isolation floor under the excitation of Floor Response A of Tohoku University

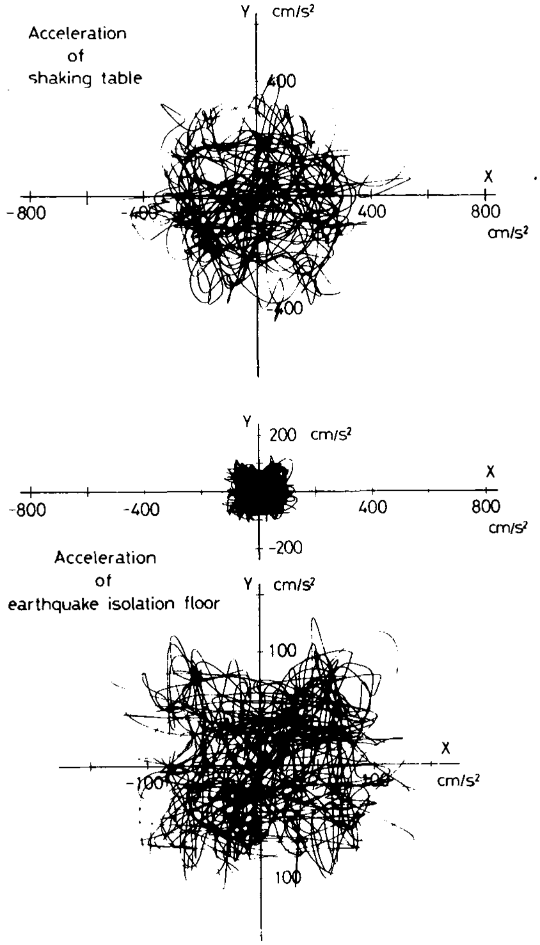

Fig. 17: Lissajour diagrams for accelerations of the shaking table and the earthquake isolation floor under the excitation of Floor Response A of Tohoku University (shown in Fig. 16)