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Seismic proving test of process computer system with a seismic floor isolation system

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1 INTRODUCTION

Role of process computer system has become important to support nuclear power plant operation. The computer system performs various kinds of information processing related to plant operations. Thus its functional capability during earthquakes is highly expected to be maintained for the inportant role in the information management.

One method of improving the seismic capability of a process computer system is to apply seismic isolation to the floor on which the computer system is installed. Using this method, the seismic force up on the computer system can be reduced, which makes it possible to improve the seismic capability of a computer system without modifying its structural system.

This paper presents the results of the seismic proving tests, undertaken at Tadotsu Engineering Center of NUPEC, of three process computer systems installed on a seismic isolation floor. At first, we investigated the function and seismic input conditions required for the seismic floor isolation system. The process computer systems were installed on a large-scale floor seismically isolated in the horizontal direction. Seismic excitation tests were carried out by using the 1000ton shaking table. The isolation performance of the floor and the functional capability of the computer systems were evaluated by the seismic vibration tests. Further, vibration analyses of the isolation floor were carried out and the design method for a process computer system combined with a seismic floor isolation system was evaluated from the test results and the analyses.

Note here that the seismic proving tests were carried out as a NUPEC project sponsored by MITI in Japan.

2 DESIGN OF SEISMIC FLOOR ISOLATION SYSTEM

2.1 Design Input Conditions

The following seismic input waves were used as design input conditions.

1) S1 wave, which is one of the seismic design earthquakes used in Japan for standardized LWR plant design.
2) S1(L) wave, which is made predominant in the long period component in view of

the particularity that a dominant vibration period of the seismic floor isolation system is long.

2.2 Function of a Seismic Floor Isolation System

The function required for the seismic floor isolation system is described as follows:

1) The floor works as a vibration isolator for large earthquake inputs but does not response to small-magnitude ones.
2) The maximum response acceleration of the floor is less than 2.50 m/sec^2 in the horizontal and vertical directions respectively.
3) Floor response spectrum of acceleration is less than the prescribed value shown in Fig.1 in the horizontal direction.

The condition described in item 2 was employed by considering the seismic condition widely used for conventional process computer systems. The response spectrum in item 3 was determined as the interface condition between the computer system and seismic floor isolation system. The conditions described in item 3 and in items 2 and 3 are hereinafter referred to as "design response spectrum" and "seismic design conditions", respectively. The "seismic design conditions" were determined from careful considerations of several types of nuclear power plants, several kinds of site conditions and input waves of design earthquake. The "seismic design conditions" are useful for the following that the method would make it possible to design independently computer systems and seismic floor isolation systems. If the conditions described in items 2 and 3 are satisfied, we are able to use the current design practice of process computer systems without any modification in designing process computer systems and computer related equipments installed on the seismic isolation floor systems.

3 STRUCTURE OF SEISMIC FLOOR ISOLATION SYSTEM

Figure 2 shows an overview of the seismic isolation floor system with three computer systems mounted on the shaking table. This isolation system was composed mainly of a floor frame, ball bearing units, spring damper units and a conventional computer floor. The floor frame was made up from H-section steel beams arranged in a form of wide planar lattice. Each of ball bearing units was equipped with three ball bearings attached to the bottom surface of a circular plate. The floor frame was supported by 25 ball bearing units, allowing it to freely move in any horizontal direction. Figure 3 shows upper and side views of the spring damper unit. Four pre-tensioned coil springs and one oil damper were connected over a pair of sliders which moved in the direction along the long side of the base plate but not moving toward each other from their initial positions. The sliders were installed to the floor frame. Thus the floor frame exhibited a nonlinear restoring force and a damping force in the horizontal direction. The spring constant of the coil spring was designed for the equivalent natural period of the seismic floor isolation system to be 3 seconds. The damping coefficient of the oil dampers was determined in accordance with its damping factor of 0.02. The trigger acceleration level was set at 0.2 m/sec^2 by using pre-tension force of the coil springs.

4 TESTS AND RESULTS

4.1 Static Tests

Static test was performed to confirm the restoring force of the spring system installed in the seismic floor isolation system. The floor frame was pushed and pulled by using two oil hydraulic actuators and we measured the displacement and the force given to the floor. Figure 4 shows the restoring force character against the floor displacement produced in the direction along the one side of the floor.

4.2 Seismic Excitation Tests

Seismic excitation tests were performed for the following items:

1) To confirm that the responses of the seismic floor isolation system for S1 and S1(L) waves are within the "seismic design conditions".
2) To confirm that the computer systems can maintain its required function during seismic excitation tests.
3) To investigate the seismic response property of the seismic floor isolation system with the computer systems.

Accelerations of the floor frame were measured at 24 points for the horizontal direction response and at 25 points for the vertical direction. Figure 5 shows one example of the time history response of the seismic isolation floor and the computer system. Table 1 shows the maximum response magnitude of the seismic isolation floor for S1(L) wave inputs. The response obtained in the case of the horizontal excitation but not including vertical excitation component was the almost same level as that in the case of horizontal and vertical 2d-excitation.

The computer systems installed on the seismic isolation floor maintained its function during the seismic excitation in all of the test cases. Figure 1 shows response spectrum of the isolation floor acceleration in the case of S1(L) wave excitation, where the thick solid line is "design response spectrum".

From the test results, it was confirmed that the maximum response acceleration and the response acceleration spectrum of the seismic isolation floor satisfied the "seismic design conditions" for S1(L) wave input.

5 VIBRATION ANALYSIS

5.1 Analytical Model

We used the following analytical models for the seismic floor isolation system which were modeled based on the results of the vibration tests.

One analytical model was a single degree-of-freedom system (Model A) and the other was 2 degrees-of-freedom system (Model B) shown in Fig.6 and Fig.7, respectively. In Model A, a whole structure on the floor frame was considered as a single rigid body. In Model B, the 1st in-plane vibration mode for the floor frame structure was taken into account in our consideration. In Fig.6, X_0, X and M express the horizontal acceleration for the ground, the relative displacement of the floor frame against the ground and the total mass of the floor frame and a whole structure installed

on the floor frame. C, f and F express the damping coefficient for the oil hydraulic dampers of the spring damper units, the frictional force for the ball bearing units and the restoring force for the spring damper units. The restoring force characteristic for the spring damper units shown in Fig.4 was used to evaluate F and f. In Fig.7, the mass M of Model A was divided into M_1 and M_2. X_1 and X_2 for the mass M_1 and M_2 express the relative displacements for the one side and the center of the the floor frame, respectively. k and C_2 express the equivalent spring constant and damping coefficient for the 1st in-plane vibration mode (about 22Hz) of the floor frame. The value for the 1st mode damping ratio (about 0.09) measured in the vibration tests was used as the value for C_2.

5.2 Analytical Results

Analytical results for the response in the horizontal direction were as follows:
The maximum response acceleration of the center of the floor frame and the maximum response in the relative displacements of the side of the floor frame for various acceleration input levels of S1(L) wave are shown in Fig.8. The acceleration floor response spectra at the center of the floor frame for the same input are shown in Fig.9. In these figures, The analytical results using Model A and Model B agree well with the experimental results. Note here that there is a slight difference in the results between Model A and Model B in the region of high frequency.

6 CONCLUSION

1) Seismic design method is proposed for interfacing seismic isolation floors and computer systems. In this method, the computer system and the seismic isolation floor are designed independently by interfacing the criteria of "seismic design conditions" established in this study.
2) The seismic floor isolation system sufficiently reduced the seismic force for the process computer systems installed on the floor. Specifically, the seismic floor isolation system could satisfy the "seismic design conditions" required to the seismic isolation. Furthermore, the functional capability of the computer systems against S1(L) large earthquake were verified when they were installed on the seismic floor isolation system.
3) In the analytical method for the horizontal direction motion of the isolation floor, it was confirmed that the proposed analytical model, that is, the single degree-of-freedom system or the 2 degrees-of-freedom system holds a sufficient applicability.

Table 1 Maximum response acceleration of floor frame for S1(L) waves

Level	Response Direction	Excitation Direction		
		Horizontal	Vertical	Hor. & Ver.
1/1	Horizontal	1.47 m/s²	0.07 m/s²	1.46 m/s²
	Vertical	0.55 m/s²	2.08 m/s²	2.04 m/s²
2/3	Horizontal	1.31 m/s²	0.06 m/s²	1.28 m/s²
	Vertical	0.54 m/s²	1.53 m/s²	1.44 m/s²
1/3	Horizontal	0.63 m/s²	0.04 m/s²	0.63 m/s²
	Vertical	0.23 m/s²	0.77 m/s²	0.84 m/s²

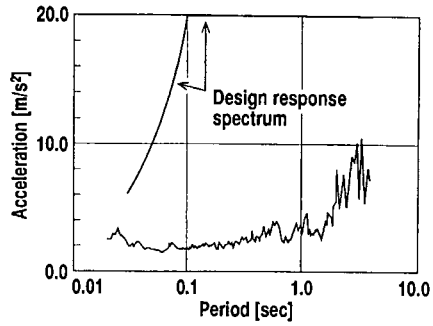

Fig. 1 Response spectrum of the floor frame in the horizontal direction for S1(L) wave input

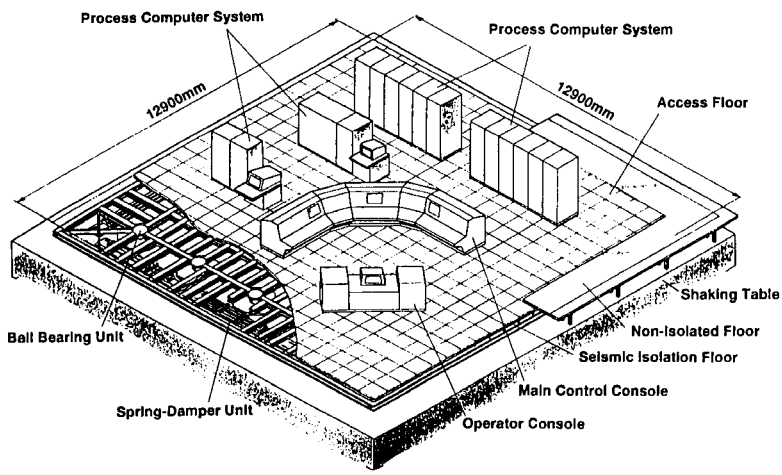

Fig. 2 Overview of the seismic isolation floor test model

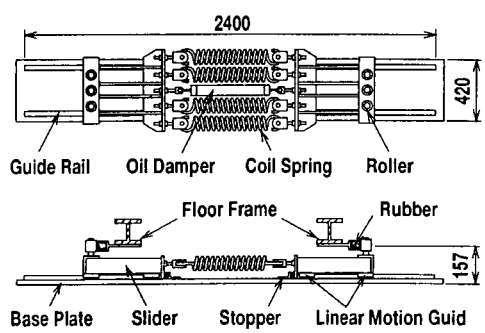

Fig. 3 Spring damper unit

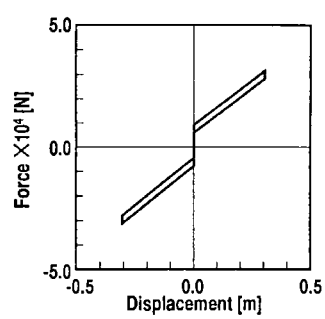

Fig. 4 Restoring force property of the seismic isolation floor

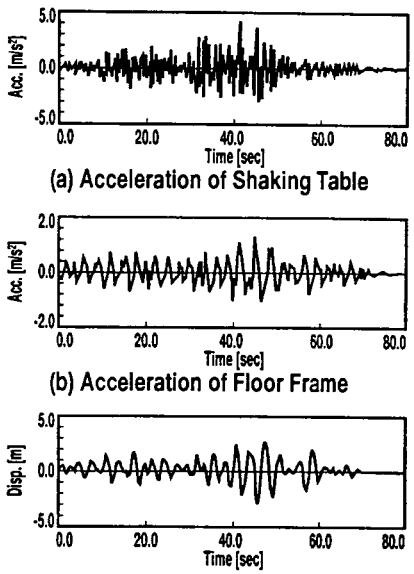

Fig. 5 Response time histories of the seismic isolation floor for S1(L) wave input

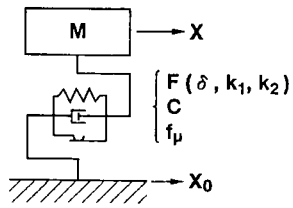

Fig. 6 Analytical model A in the horizontal direction

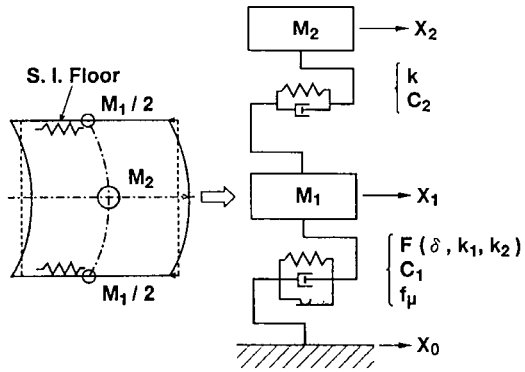

Fig. 7 Analytical model B in the horizontal direction

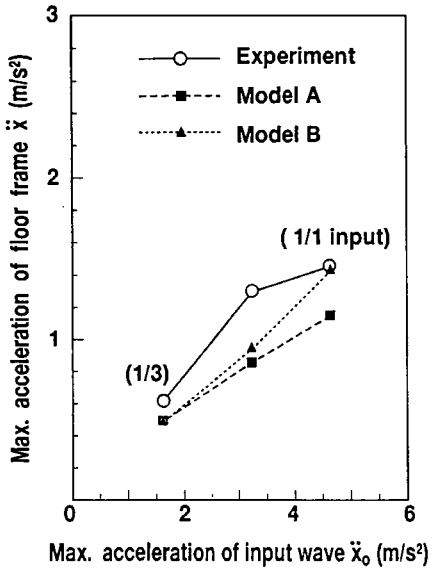

Fig. 8 Maximum response acceleration of the floor frame for S1(L) waves

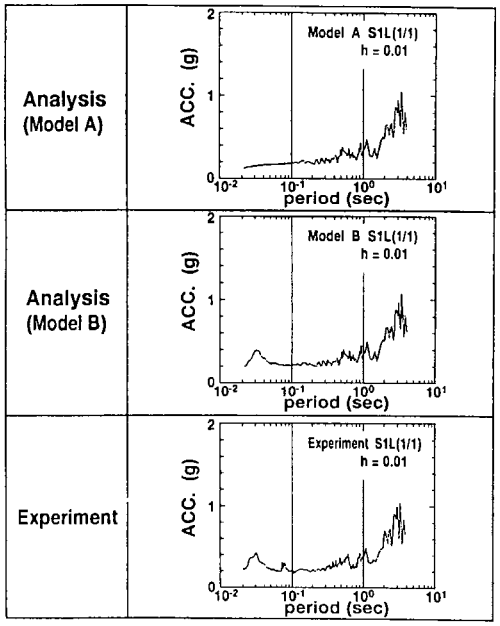

Fig. 9 Floor response acceleration spectra on the floor frame for S1(L) wave