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STUDY ON THE APPLICATION OF SEISMIC ISOLATED FLOORS FOR NUCLEAR POWER PLANTS

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1. INTRODUCTION

To improve the safety of nuclear power plants during an earthquake, it has been proposed to install seismic isolated floors in parts of a plant which are difficult to strengthen sufficiently to withstand seismic forces. As a typical area of this kind we selected the main control room, designed 3-dimensional seismic isolated floors for it, and made a layout study. Vibration tests were carried out on a model to confirm the effectiveness of the seismic isolated floors.

2. EVALUATION OF THE EFFECTIVENESS AND DESIGN OF SEISMIC ISOLATED FLOORS FOR NUCLEAR POWER PLANTS

The CRTs in the main control board are not qualified to withstand S_2 earthquakes in present plants. If we install seismic isolated floors in the main control room, the CRTs can withstand the forces of S_2 earthquakes, and we can take credit for their use after an S_2 earthquake.

In order that the CRTs in the main control board can continue to function after S_2 earthquakes, it is necessary to reduce the response accelerations in both the horizontal and vertical directions to less than 250gals.

We evaluated the function and the performance of seismic isolated floors during S_2 earthquakes(input acceleration:about 500 gals) by analyses using a single mass model. (reference(1)) The results of the horizontal response analyses are shown in Fig. 1. The target is to reduce the acceleration to less than 180 gals for conservatism because the maximum accelerations measured in tests exceeded those of the analyses by a factor of about 1.3 in a past study.(reference (2)) (250/180≒1.38) The allowable displacement is less than 40 cms and the allowable damping coefficient is less than 70%. These limiting the conditions can be

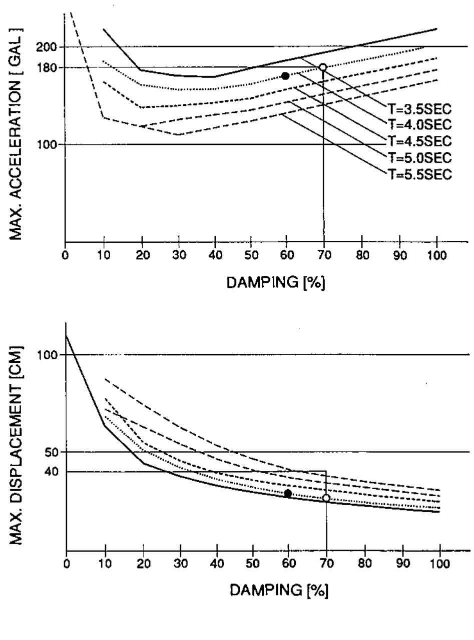


Fig. 1 Results of horizontal response analyses

satisfied for some range of damping coefficients if the natural period of the isolated floors is between 3.5 to 5.5 secs. In the diagram, the point marked ○ gives the minimum displacement in the allowable range of damping coefficients and natural periods. The point marked ● was selected for the design of the floors to allow for variations in the damping coefficient. Vertical analyses were performed, and evaluated in the same way. Based on the simulation analyses of the isolated floors, the design specifications were decided as shown in Table 1.

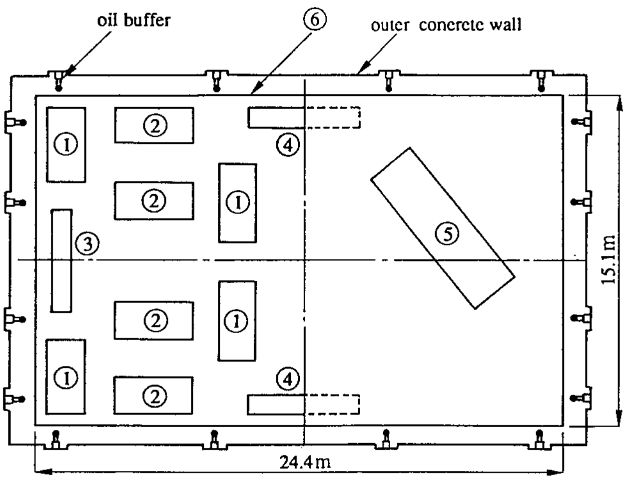
Table 1. Design specifications of the isolated floors

item	horizontal	vertical
natural period	4 sec	1 sec
damping coefficient	60 %	40 %
friction coefficient	0.01	0.04

3. THE LAYOUT STUDY OF ISOLATED FLOORS FOR NUCLEAR POWER PLANTS

We studied a suitable layout for the main control room of the next PWR plant under design, and designed the 3-dimensional seismic isolated floors.

The resultant layout of the seismic isolating devices is shown in Fig. 2, and a cross section is shown in Fig. 3. We must consider the seperation between A train and B train safety cables and between safety and non-safety cables to provide fire protection. So, we installed the floor cable ducts,made of concrete as in the present design, on the isolating devices. As the seismic isolation can allow a relative displacement of 40 cms, we provided a gap of 1 m between the isolated floors and the outer concrete wall and installed friction panels between them. It is difficult technically to use 3-dimensional isolated floors for the whole area of the main control room and there are also design difficulties in adopting friction panels to the main control board.



layout of horizontal devices   layout of vertical devices

Fig. 2 Layout of seismic isolating devices

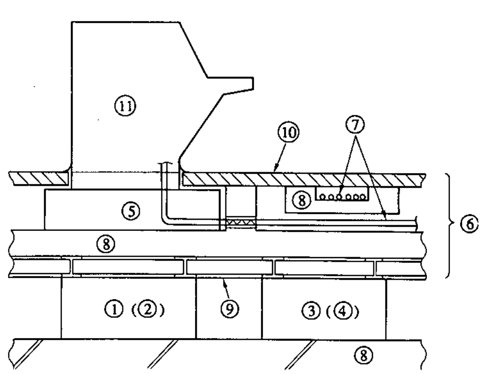


Fig. 3 Cross section

Therefore, the isolating devices for the horizontal direction are installed for the whole area of the main control room(area⑥), and the devices for the vertical direction are installed for two main control boards. (⑤) Also, we install oil buffers around the isolated floor in case the displacement exceeds the design value. We installed spring and damper units separately in order to reduce the height of the floor.
The horizontal isolating devices consist of spring units(①, ②), and damper units(③, ④)for the X and Y directions. Each unit has an orthogonally coupled linear motion mechanism,therefore, the upper parts of the units can move in any horizontal direction. The details of the spring unit and the damper unit are shown in Fig. 4 and Fig. 5 respectively. The details of the vertical isolating units are shown in Fig. 6. Links and guide rollers prevent rocking motion of the vertical isolating devices.

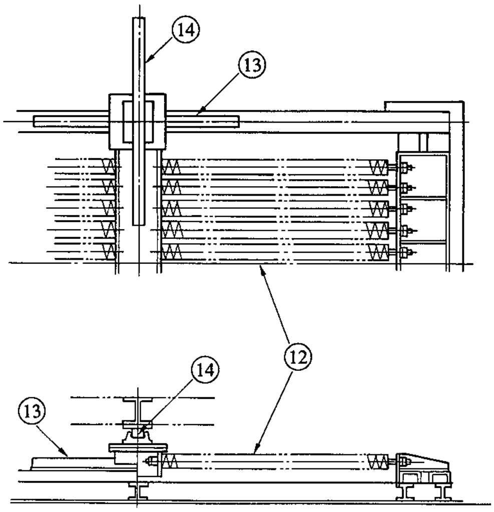


Fig. 4 The details of the spring unit

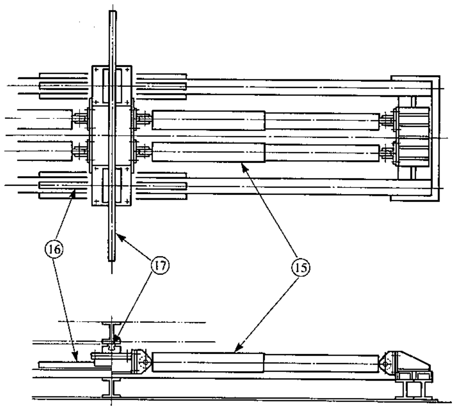


Fig. 5 The details of the damper unit

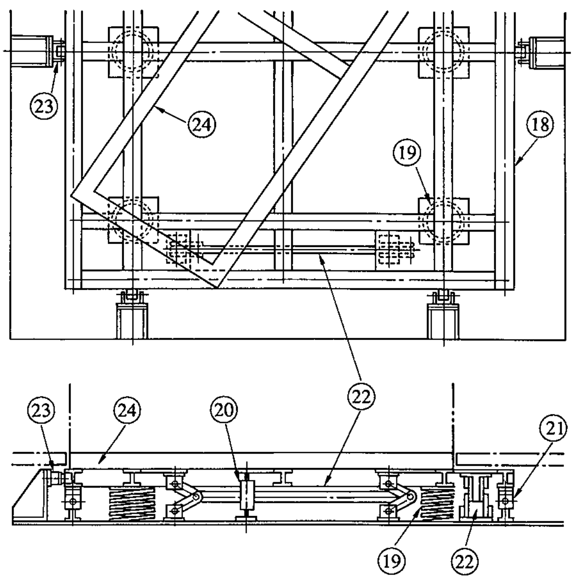


Fig. 6. The details of the vertical isolating unit

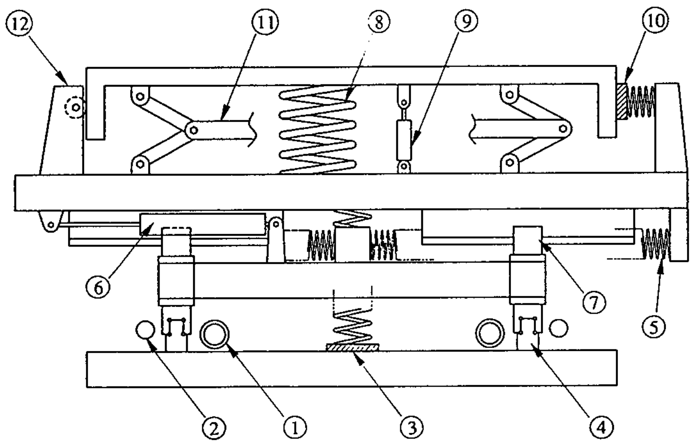
①:spring unit for x direction
②:spring unit for y direction
③:damper unit for x direction
④:damper unit for y direction
⑤:vertical isolating unit
⑥:horizontal isolating area
⑦:cables
⑧:concrete
⑨:H-beam
⑩:floor panel
⑪:main control board
⑫:horizontal spring
⑬:rail roller for x direction
⑭:rail roller for y direction
⑮:horizontal oil damper
⑯:rail roller for x direction
⑰:rail roller for y direction
⑱:frame
⑲:vertical spring
⑳:vertical oil damper
㉑:vertical friction damper
㉒:link
㉓:guide roller
㉔:frame

4. VIBRATION TEST OF A MODEL

We designed and manufactured a test model for the 3-dimensional floor isolating devices, and performed sinusoidal characteristic and seismic response vibration tests in the Chiba Experiment Station of University of Tokyo.

4.1 TEST MODEL CONFIGURATION

The fundamental configuration of the test model for the 3-dimensional floor isolating devices is shown in Fig. 7. The experimental setup for the vibration test using a two dimensional shaking table is shown in Fig. 8. The size of the table is 3m × 3m. Due to its limitations, the test model is a combination of spring and damper units, but, the natural period, damping coefficient, and friction coefficient of the test model are the same as those of the main control room of an actual plant.
A model which simulates the weight and vibration chacteristics of a main control board is loaded on the test model.



①:spring for x dir.
②:oil damper for x dir.
③:friction damper for y dir.
④:rail roller for x dir.
⑤:spring for y dir.
⑥:oil damper for y dir.
⑦:rail roller for y dir.
⑧:spring for z dir.
⑨:oil damper for z dir.
⑩:friction damper for z dir.
⑪:link
⑫:guide roller

Fig. 7 The fundamental configuration cf the test model

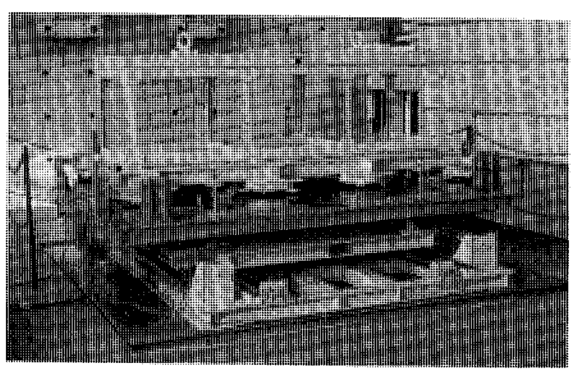


Fig. 8 Experimental setup of the vibration test

4.2 VIBRATION TEST AND RESULTS

The location of instruments for the vibration test is shown in Fig. 9. Typical expreimental data are shown in Fig. 10. Fig. 11 shows the horizontal and vertical response accelerations and displacements of the test model. As shown in Table 2, the response accelerations of the test model are less than the allowable 250 gals, and, we could comfirm the acceptable performance of the isolated floors during an earthquake.

Table 2. Performance of the isolating devices

Wave name	S_2 earthquake input acceleration	Maximum response acceleration	Allowable acceleration
EL CENTRO NS	450 gals	98 gals	250 gals
EL CENTRO EW	450 gals	96 gals	250 gals
AKITA NS	450 gals	150 gals	250 gals
AKITA EW	450 gals	113 gals	250 gals
EL CENTRO UD	779 gals	218 gals	250 gals
AKITA UD	366 gals	175 gals	250 gals

* For the vertical direction,the floor response waves were used in the analysis.

4.3 REFLECTION OF THE TEST RESULTS INTO THE DESIGN

Based on the experience of these tests, changes in each of the parameters relative to the design conditions can be expected as follows:

- natural period: same as the design condition
- damping coefficient: $\pm 15\%$
- friction coefficient: $-12\% \sim +25\%$

We should reflect the fluctuations of such parameters into the design of the isolated floors of an actual plant.

5. AKNOWLEDGEMENTS

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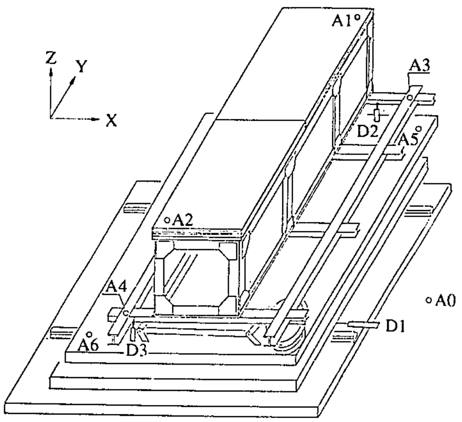

A0:acceleration on the shaking table
A1,A2:acceleration on the model which simulates a main control board
A3,A4:acceleration on the vertical isolating device
A5,A6:acceleration on the horizontal isolating device
D1:relative displacement between the horizontal isolating device and the shaking table
D2,D3:relative displacement between the vertical isolating device and the horizontal isolating device

Fig. 9 Location of measuring instruments for the viblation test

EL CENTRO EW

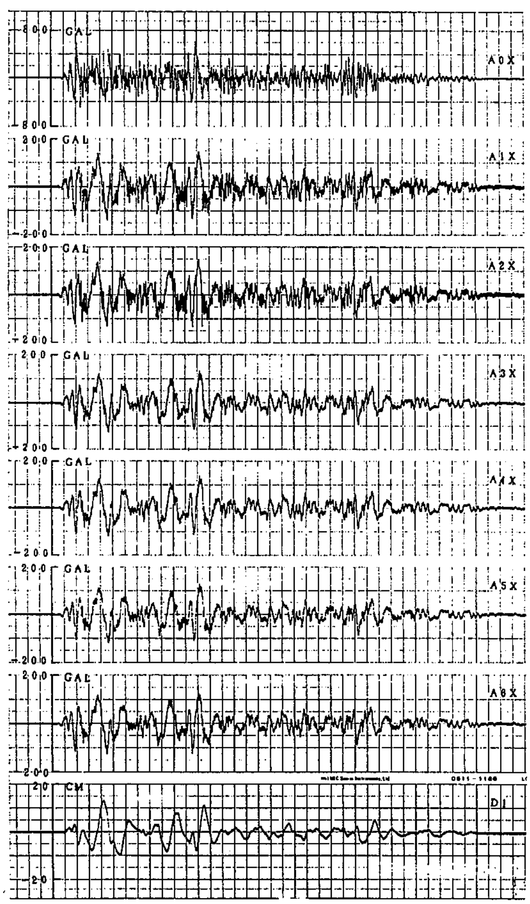

Fig. 10 Typical experimental data

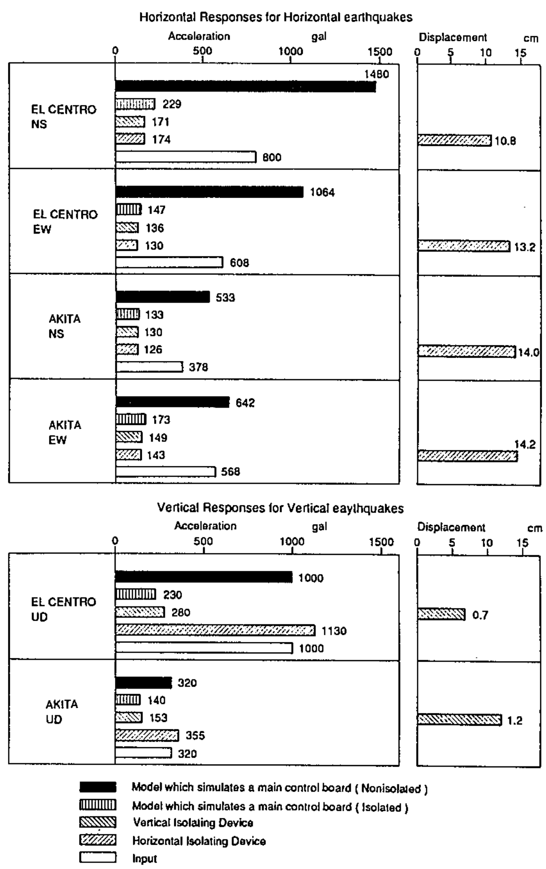

Fig. 11 Horizontal and vertical response accelerations and displacements of the test model