Copyright © 1996 Elsevier Science Ltd
Paper No. 1440. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

FUNDAMENTAL STUDY OF THREE-DIMENSIONAL SEISMIC ISOLATION SYSTEM FOR NUCLEAR POWER PLANTS

T. FUJITA
Institute of Industrial Science, University of Tokyo
7-22-1, Roppongi, Minato-Ku, Tokyo 106, Japan

S. FUJITA
Department of Mechanical Engineering, Tokyo Denki University
2-2, Kanda-Nishiki-Cho, Chiyoda-Ku, Tokyo 101, Japan

Y. WATANABE and A. KATO
Civil Engineering and Architectural Department, The Japan Atomic Power Company
1-6-1, Ohtemachi, Chiyoda-Ku, Tokyo 100, Japan

S. SUZUKI and K. FUKUMORI
Research and Development Department, Bridgestone Corporation
3-1-1, Ogawa-Higashi-Cho, Kodaira-City, Tokyo 187, Japan

ABSTRACT

To investigate feasibility of application of the three-dimensional seismic isolation to nuclear power plants, an isolation system which consisted of rubber bearings for the horizontal isolation and coned-disc springs for the vertical isolation, was tested. Through excitation tests, it was shown that the isolation system was effective to equipment in the base-isolated building in the vertical direction as well as the horizontal one, and a rotational motion of the building due to the vertical isolation was perfectly suppressed, although the isolation system was ineffective to the building itself in the vertical direction.

KEYWORDS

Seismic isolation; three-dimensional isolation; nuclear facility; rubber bearing; multistage rubber bearing; coned-disc spring; shake table test; building; equipment; isolation performance.

INTRODUCTION

Few attempts have been made for three-dimensional seismic isolation of buildings so far, because it is difficult to suppress dangerous rotational motion of the building accompanying the vertical isolation. However the three-dimensional seismic isolation is becoming desirable for nuclear power plants, particularly, FBR plants in which vertical seismic responses of the reactor buildings are crucial to structual design of the main components as wel as the horizontal ones (Tokuda *et al.*, 1995; Beliayev and Vinogradov, 1995). Therefore a fundamental study has been carried out to investigate feasibility of application of the three-dimensional seismic isolation to nuclear power plants.

In the study, an three-dimensional isolation system which consists of rubber bearings for the horizontal isolation and coned-disc springs for the vertical isolation, has been tested. The coned-disc springs can provide the superstructure with a low vertical natural frequency together with a friction damping force for the vertical isolation. The object of this study is to examine effectiveness of the isolation system through excitation tests of a building model supported by experimental models of the isolation system.

EXPERIMENTAL MODEL

As shown in Figs. 1 and 2, excitation tests were carried out for a two-story steel frame building model supported by 4 experimental models of the isolation system. The building model of a 6,000 kg total mass, had a 0.5 Hz horizontal 1st-mode natural frequency and a 3.0 Hz vertical 1st-mode natural frequency when isolated, while the superstructure had a 10 Hz horizontal 1st-mode natural frequency and a vertical one higher than 50 Hz when non-isolated. For the vertical isolation, the 3.0 Hz natural frequency was chosen to prevent the large

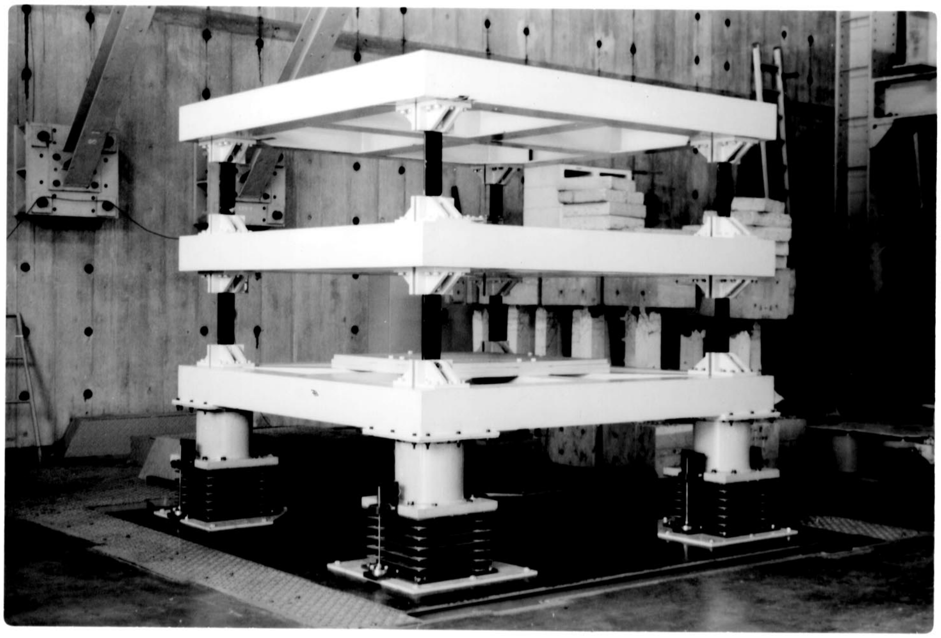

Fig. 1. Base-isolated building model using the three-dimensional isolation system

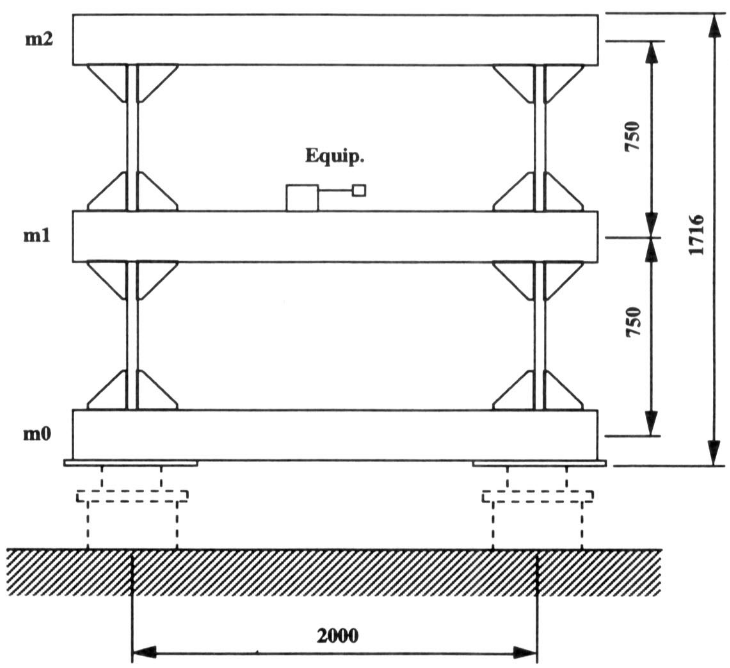

Fig. 2. Schematic drawing of the base-isolated building model

rotational motion of the building. As shown in Fig. 2, a simple equipment model having a 10 Hz vertical natural frequency was attached on the 2nd floor (intermediate floor) of the building.

Figure 3 shows the experimental model of the isolation system in which a coned-disc spring was mounted on a multistage rubber bearing. The multistage rubber bearing consists of a number of stages (each stage comprising 4 laminated rubber bearing elements) piled up with stabilizing plates between the stages. This type of rubber bearing was developed for seismic isolation of light structures and equipment (Fujita *et al.*, 1987). In the experimental model, the rated mass of 1,500 kg was too light to use normal rubber bearings. Consequently the multistage rubber bearing was used to provide the rated mass with a 0.5 Hz horizontal natural frequency and to accept a horizontal displacement up to about 0.2 m. Steel-bar dampers of a 0.1 yielding coefficient were used to produce a damping force for the horizontal isolation. The coned-disc spring had a restoring force shown in Fig. 4, and provided the rated mass with a 3.0 Hz vertical natural frequency and a vertical friction force of 8% of the rated lode.

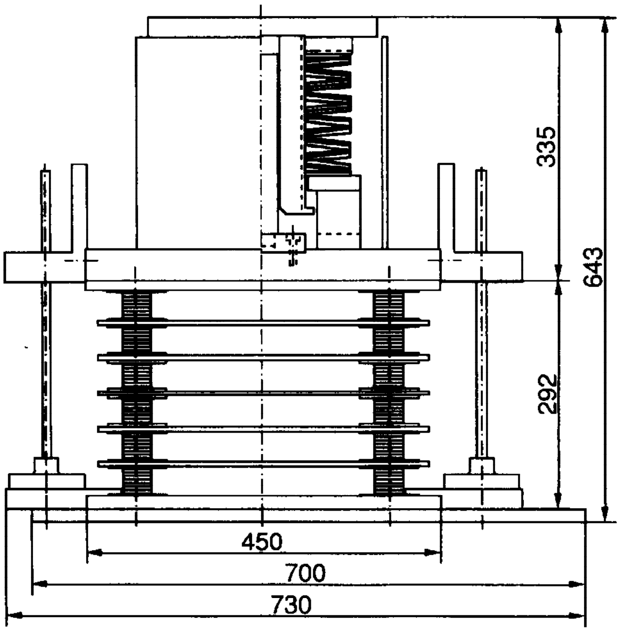

Fig. 3. Experimental model of the three-dimensional isolation system

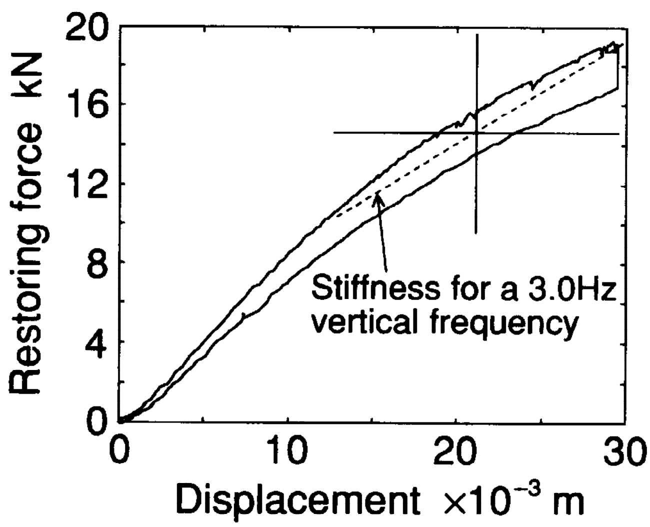

Fig. 4. Restoring force of the coned-disc spring

ISOLATION PERFORMANCE FOR BUILDING

Two-dimensional, horizontal-vertical, excitation tests were carried out, using various earthquake inputs including ground motion records and artificial ground motion time histories based on a tentative design earthquake proposed for a base-isolated FBR plant.

Figures 5 and 6 show the test results for the El Centro NS-UD input and the artificial earthquake H-V input respectively. In each figure, the horizontal and vertical response accelerations of the building and the vertical response accelerations of the equipment model when isolated and when non-isolated are compared. For the horizontal isolation, both of the results confirmed good isolation performance of the system equal to normal horizontal base-isolation systems. For the vertical isolation, satisfactory reduction was obtained in the response acceleration of the equipment model when isolated, although the response acceleration of the building when isolated was slightly reduced in the El Centro case and somewhat amplified in the artificial earthquake case.

Figures 5 and 6 also show the horizontal displacement of the rubber bearings and the total vertical displacement of the coned-disc springs together with the vertical one due to the rotational motion of the superstructure.

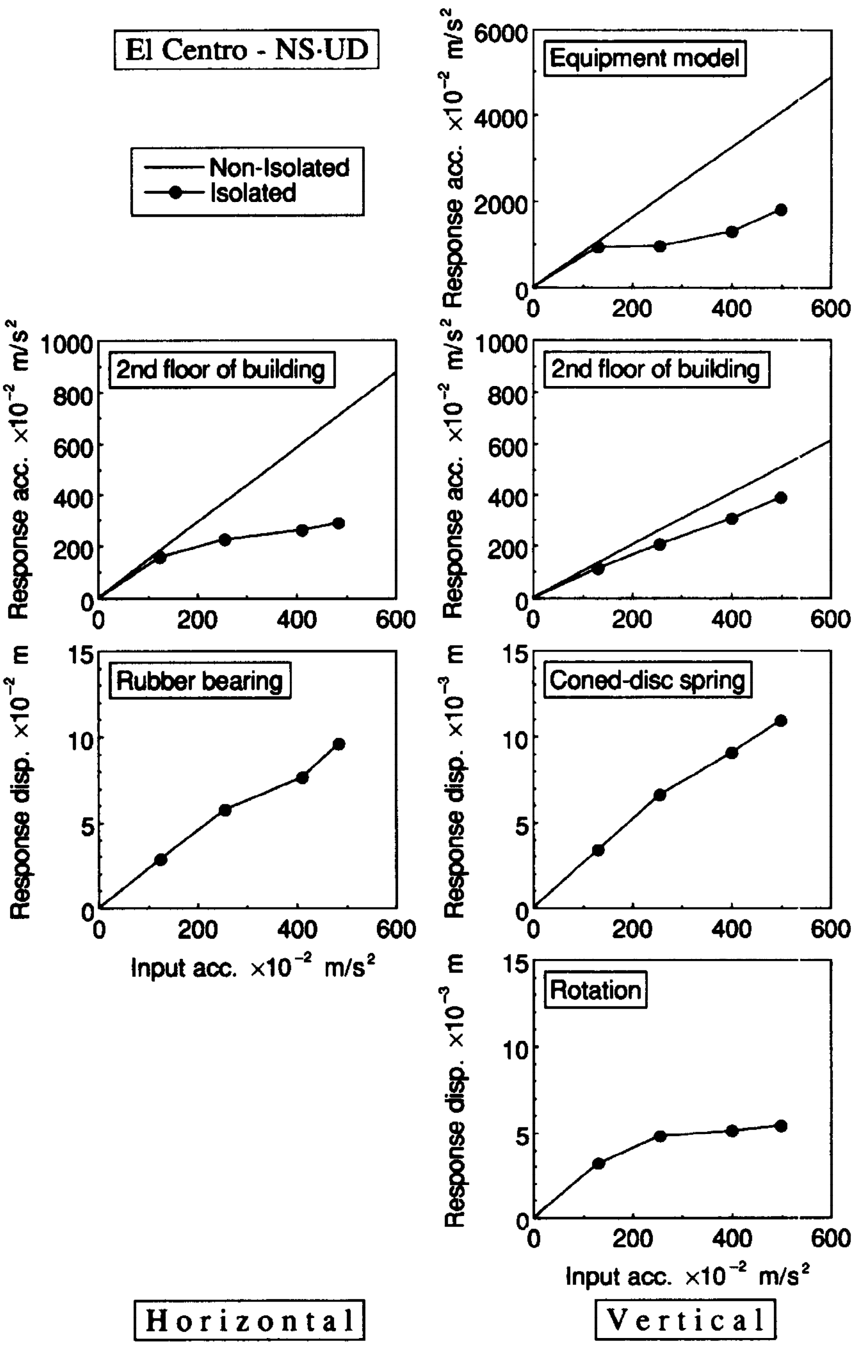

Fig. 5. Isolation performance in the case of El Centro NS-UD input

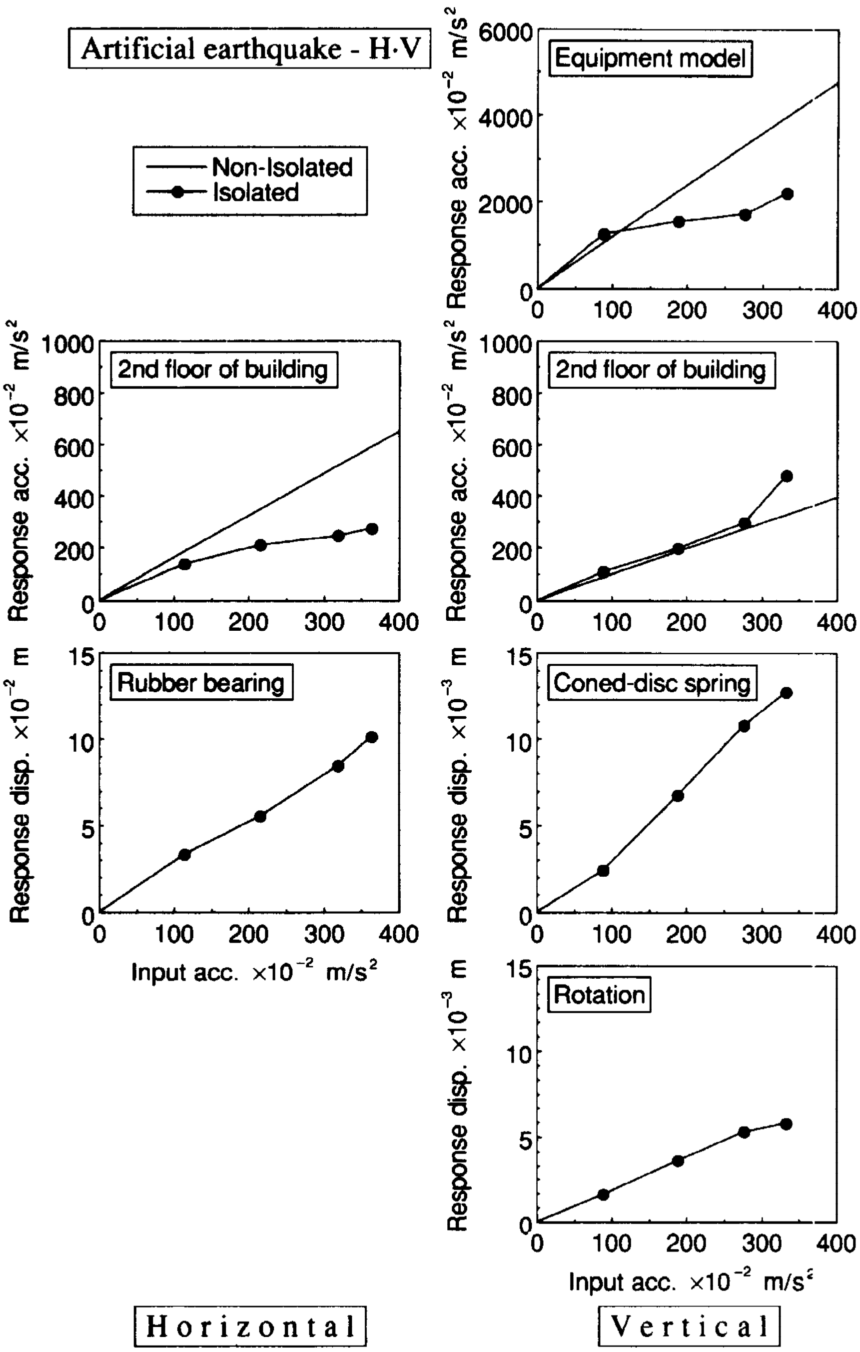

Fig. 6. Isolation performance in the case of the artificial earthquake H-V input

ISOLATION PERFORMANCE FOR EQUIPMENT IN THE BUILDING

The floor response spectra of vertical accelerations on the 2nd floor of the building when isolated and when non-isolated are shown in Fig. 7 for the El Centro NS-UD input and Fig. 8 for the artificial earthquake H-V input, which show the effectiveness of the systems to equipment with natural frequencies of a wide range.

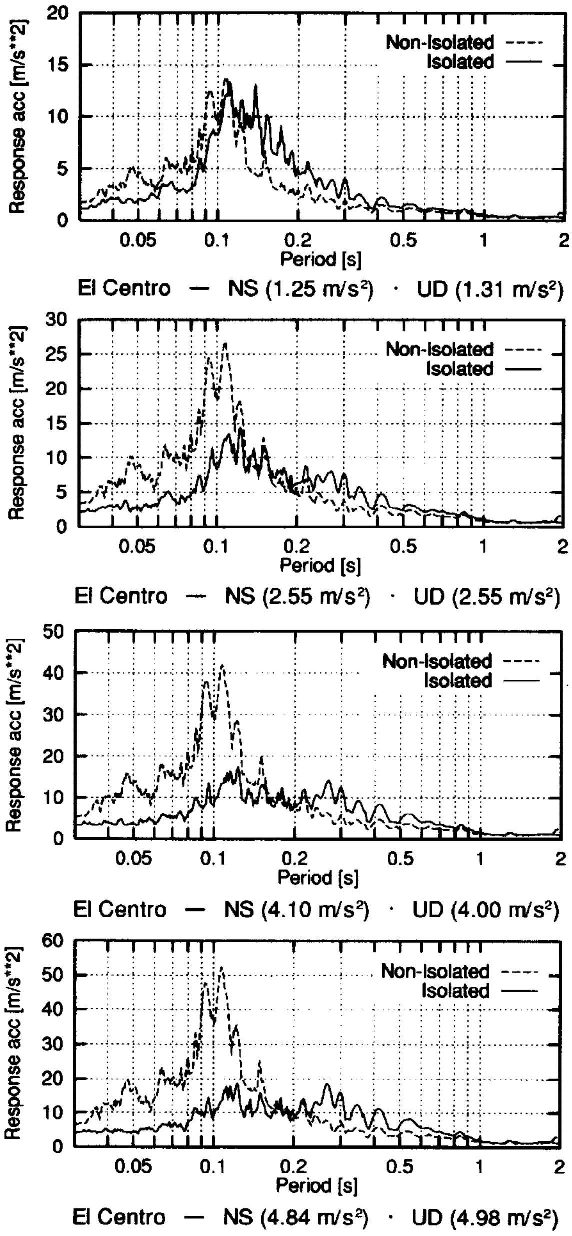

Fig. 7. Floor response spectra of vertical floor accelerations of the building in the case of El Centro NS-UD input (1% damping)

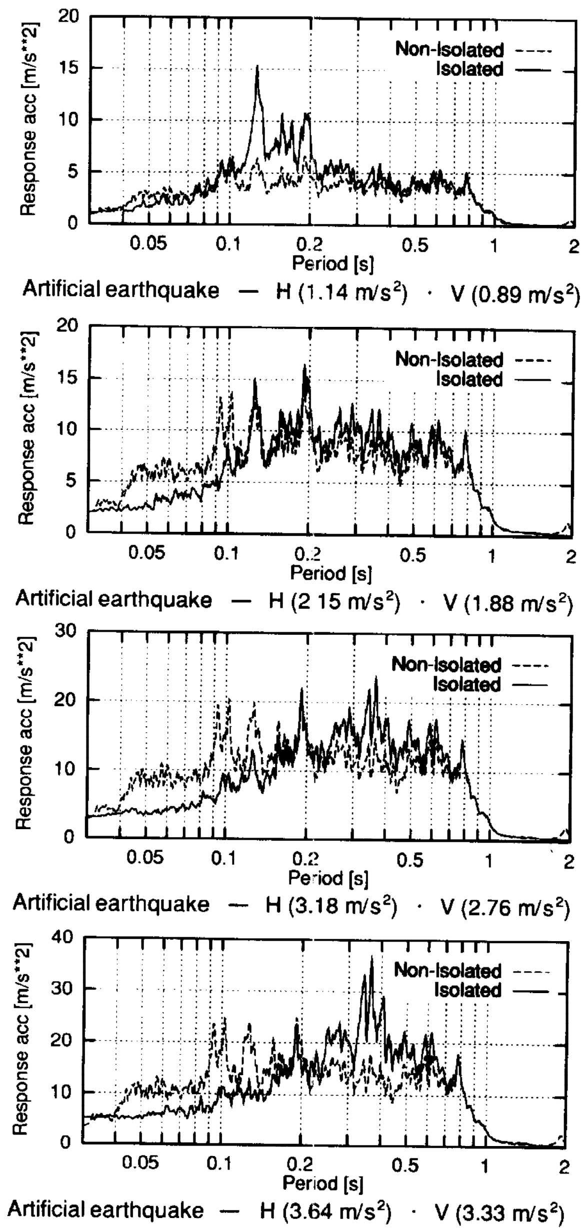

Fig. 8. Floor response spectra of vertical floor accelerations of the building in the case of the artificial earthquake H-V input (1% damping)

ROTATIONAL MOTION OF THE BUILDING DUE TO THE VERTICAL ISOLATION

Figures 9 and 10 show time histories of the vertical displacements of the coned-disc springs on the both sides in the excitation direction, the vertical ones due to the translation and the rotation of the superstructure and the horizontal displacement at the center of gravity of the superstructure. The tests confirmed that the rotational motion of the building could be almost perfectly suppressed. This result is very important for implementation of the system.

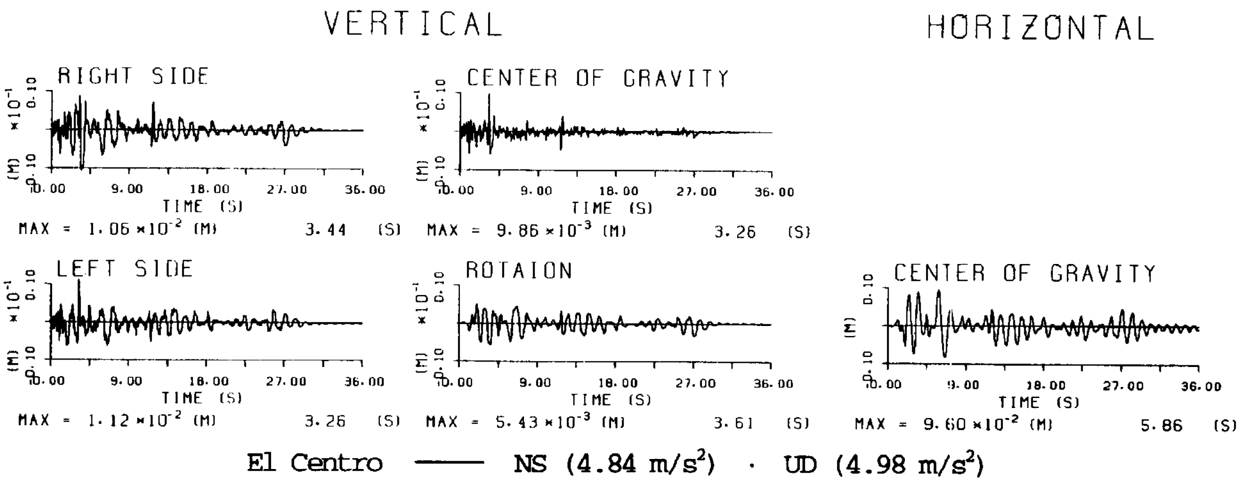

Fig. 9. Time histories of the vertical and horizontal displacements in the case of El Centro NS-UD input

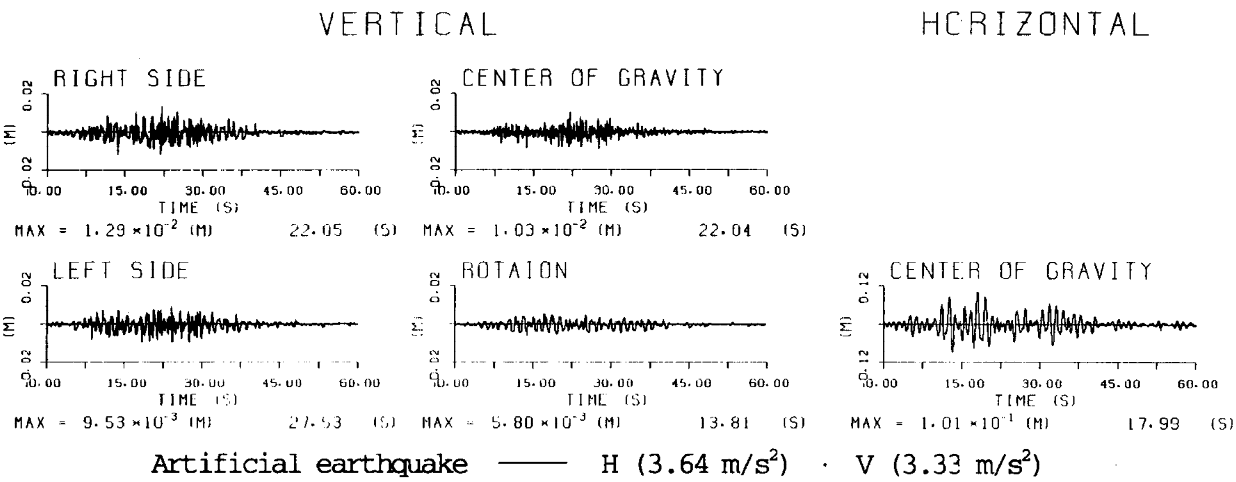

Fig. 10. Time histories of the vertical and horizontal displacements in the case of the artificial earthquake H-V input

CONCLUSIONS

The following conclusions were obtained:

(1) The isolation system was effective to equipment in the base-isolated building in the vertical direction as well as the horizontal one.

(2) The rotational motion of the building accompanying the vertical isolation was perfectly suppressed, although the isolation system was ineffective to the building itself in the vertical direction.

ACKNOWLEDGMENT

The authors are grateful to Mr. H. Kurabayashi, Mr. N. Sone and Mr. T. Omi of Mitsubishi Steel Mfg. Co., Ltd. for their cooperation through design and fabrication of the coned-disc springs used in the tests.

REFERENCES

Beliayev, V. S. and V. V. Vinogradov (1995). Optimization of power characteristics of multicomponent low-frequency system of seismic protection of building with reactor plant of VVER-600 type. *Trans. 13th Int. Conf. on Struct. Mech. in Reactor Technology* (SMiRT 13), Vol. 3, 519-522.

Fujita, T., F. Mori, N. Masaki and Y. Suizu (1987). Experimental study of multi-stage rubber bearings developed for an isolation floor for earthquakes and ambient micro-vibration. *Trans. Japan Soc. Mech. Eng.*, **53**, 490, C, 1147-1152 (in Japanese).

Tokuda, N., A. Kashiwasaki, I. Omata and T. Ohnaka (1995). Three-dimensional base isolation system for assumed FBR reactor building. *Trans. 13th Int. Conf. on Struct. Mech. in Reactor Technology* (SMiRT13), Vol. 3, 513-518.