Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.V)

7-10-15

SHAKING TEST OF SEISMIC ISOLATION FLOOR SYSTEM BY USING 3-DIMENSIONAL ISOLATOR

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SUMMARY

We have proposed a new 3-dimensinal seismic isolator, which is made from the compound construction of an air spring and a laminated rubber bearing. As one of the applications of the isolator, 3-dimensional isolation floor system has been developed for high-tech facilities. To examine the effectiveness of the system, shaking tests using floor model supported by isolators were performed. The results of shaking tests were satifactry and in good agreement with analytical ones. The effectiveness of the system using the present isolators was confirmed.

INTRODUCTION

As the computers and super-precise equipments, such as semi-conducter manufacturing equipments, have been highly advanced, it is important to protect them from earthquake attack. The use of isolation system may provide a practical resolution for the object (Refs.1,2).

As a result of being designed to withstand gravity forces, usual structures are more resistant to vertical than horizontal excitation. Some super-precise equipments, however, are easily resonat, because of its structural conditions, to vertical seismic excitation, which was not formerly taken into account in the seismic design. Accordingly, they call for the isolation from vertical as well as horizontal seismic excitations.

We have proposed a new 3-dimensinal seismic isolator which is made from the compound construction of an air spring and laminated rubber bearing (Ref.3). As one of the applications of the isolator, 3-dimensinal isolation floor system has been developed for high-tech facilities. To comfirm the effectiveness of the system, shaking tests using experimental model were performed. In this paper, the present system is described in detail and the results of shaking tests using a floor model are discussed.

COMPONENT DEVICES OF THE SYSTEM

The system consists of 3-dimensional isolators, viscous dampers, air tanks and automatic level controller and so on. Fig.1 shows the schematic diagram of the system.

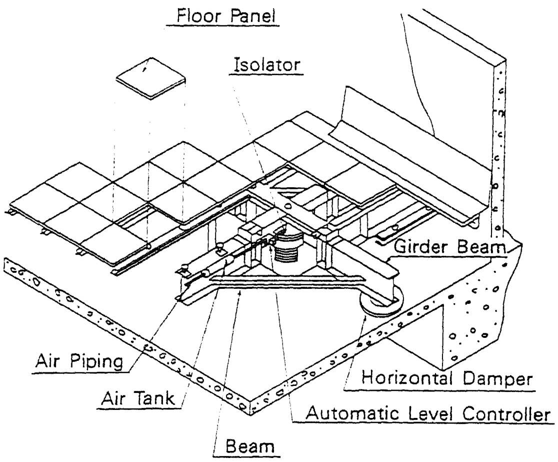


Fig.1 3-Dimensinal Isolation Floor System

The 3-dimensional isolator, the main device of the system, which is made from the compound construction of an air spring and a laminated rubber bearing, absorbs vertical vibration by the air spring, while horizontal one is primarily by the laminated rubber bearing. The present isolator is schematically shown in Fig.2.

The air spring used here is of diaphram type, which is composed of outer and inner cylindrical shells, upper and lower thick circular plates and fibre reinforced rubber membrane (Ref.4). Air springs are widely used as vibration absorbers. The flexibility of air spring is obtained by the rubber membrane and it can deform three dimensionally. It is relatively easy to obtain sufficiently large capacity of vertical deformation, but its horizontal deformation is restricted from the radius of rubber membrane. Therefore, air springs alone are unsuitable for seismic isolators, which call for large horizontal deformation capacity. The compound construction of an air spring and a laminated rubber bearing came from the idea, that the major part of the required horizontal deformation be imposed on the laminated rubber bearing, the large deformation capacity of which has been already established.

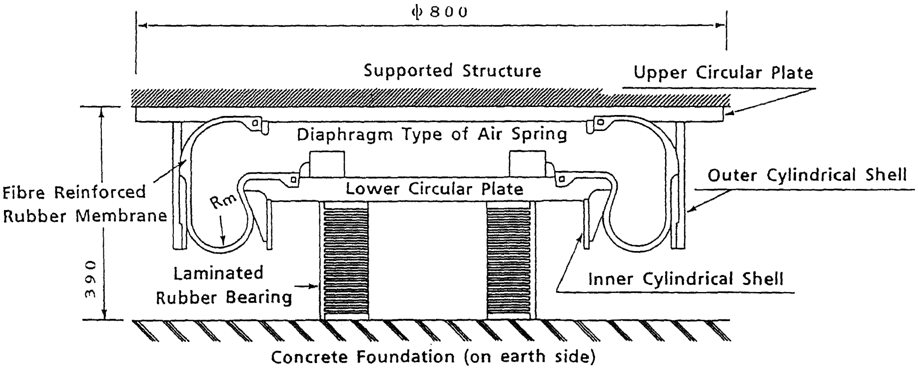


Fig.2 3-Dimensinal Isolator

One of the special features of the present isolator is that it can absorb not only earthquake but also micro-tremulous vibration. Accordingly, it serves as comprehensive isolator from various vibrations such as earthquake, traffic vibration, etc. The natural frequency of the isolator is set to be 0.7 Hz to the horizontal direction, and 1.2 Hz to the vertical one with auxiliary air tank, respectively, at the nominal load condition of 5 tons.

The dampers used in the system are the shear-type viscous damper to the horizontal direction and the air damper to the vertical. The air damping is induced by the resistance to air flow through an orifice, which is installed in the hose connecting air spring with auxiliary air tanks. By the automatic level controller, the level of the floor can be maintained at the fixed level, whenever it is changed by the variation of load on the floor.

METHOD OF SHAKING TEST

To confirm the performance of individual elements of the system (isolators, dampers, automatic level controllers) and of the total isolation system, shaking tests of the floor model were performed.

Test Model The experimental model is shown in Fig.3. The floor structure is modeled by a reinforced concrete slab as large as the shaking table, in stead of a steel framework. The experimental model is supported by four isolators, and the total weight of supported floor is about 20 tons, at the nominal load condition of four isolators.

The air spring used here is shown in Fig.2, where its air pressure is 2.5 kg/cm^2 at the nominal load, and its air volume is 24000 cm^3, and the height of isolator is 390 mm. The horizontal viscous dampers are arranged at each side of slab. Two auxiliary air tanks are used per a isolator, where one is used for adjusting vertical natural frequency and another for adjusting vertical air damping. The volume of both tanks are 39000 cm^3 and the orifices are installed in the hose between these two tanks. And automatic level controllers are connected with isolators and air tanks.

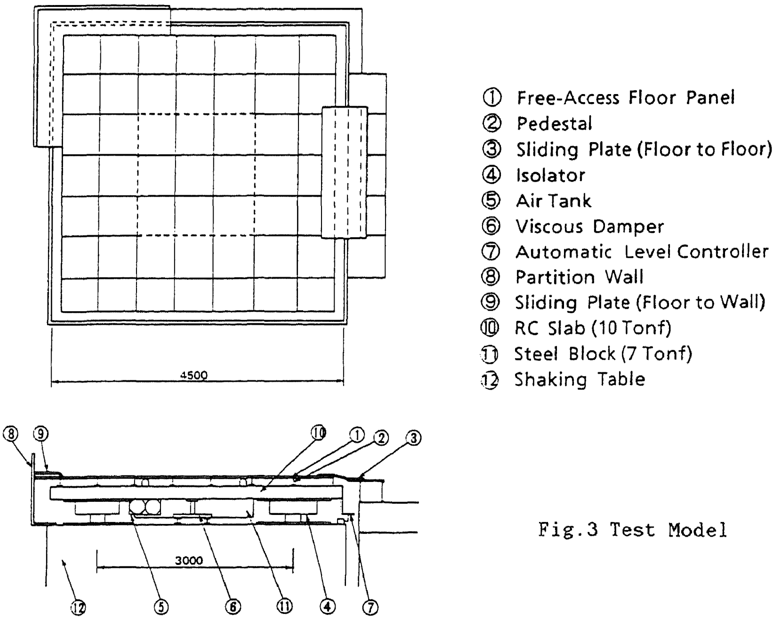
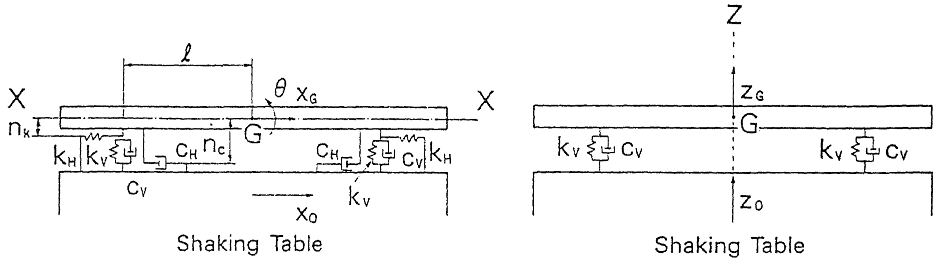


Fig.3 Test Model

Test Method The test model were set up to on 35tons 3-dimensinal shaking table at IHI Earthquake-Proof Engneering Laboratory and excited with frequency sweep and seismic waves. Seismic waves used in the tests are several real recorded waves and floor response waves produced from them. Horizontal and vertical excitation were independently or simultaneously performed.

Horizontal and vertical accelerations of test model at the center of gravity are calculated by using two horizontal and vertical accelerometers installed on the slab, respectively. And rotatinal acceleratin can be also determined by two vertical accelerometers. Relative displacements between test model and shaking table are also measured.

Representation of the Test Model Motion The behavior of test model can be treated as rigid body motion. From the symmetricity with respect to X- and Y-axes, the response of the test model can be represented by two dimensional motions. Fig.4(a) exhibits the representation of the test model motion under horizontal excitation. In this case, the coupled motion of X_G and θ , so called rocking motion, is induced. Here, X_0 and X_G indicate absolute displacements along X-axis of shaking table and test model, respectively, θ the rotational motion about Y-axis, k_H and k_V the horizontal and vertical spring stiffness of isolator, respectively, C_H and C_V the horizontal and vertical damping coefficients of dampers, respectively. The distance ℓ is a half of the horizontal one between the elastic center of two isolator units and n_K and n_C the vertical distances from the center of gravity to the elasitic center of isolator unit and the damping center of horizontal damper unit, respectively. On the other hand, the motion under vertical excitation can be simply represent by the model of a single degree of freedom, as shown in Fig.4(b), where Z_0 and Z_G indicate absolute displacements along Z-axis of shaking table and test model, respectively, and is vertical damping coefficient of vertical damper.



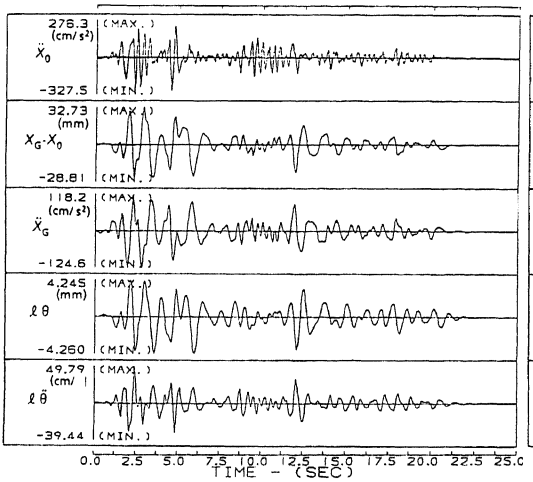
(a) Horizontal Excitation (b) Vertical Excitation

Fig.4 Representation of Test Model Motion

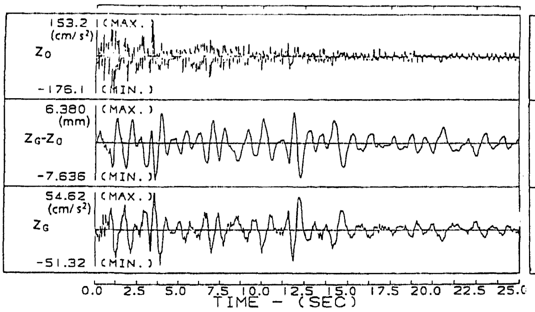
RESULTS OF SHAKING TEST AND ANALYSIS

Results of shaking tests Fig.5(a) and Fig.5(b) show the responses of test model under horizontal and vertical excitation, respectively, where the excitation waves are floor responses of El Centro-NS and -UD, considering the amplification of ground motion due to the building with its horizontal natural frequency of 3 Hz, and the maximums of ground acceleration are scaled to 180 cm/sec^2. From these results, natural frequencies of the system to the horizontal and vertical directions are 0.8 Hz (including elastic behavior of viscous dampers) and 1.2 Hz, respectively, and damping ratios are more than 20 % to both horizontal and vertical directions. It is observed that both horizontal and vertical isolation performance are excellent. The rocking motion under horizontal excitaion is sufficiently reduced by vertical air dampers and is not obstruction for practical use of the present system.

Comparison of Test Results with Analytical ones The analytical results used calculation models as shown in Fig.4 were performed to be compared with experimental ones. The spring and damping elements used in the analysis are modeled as linear spring constants and equivalent damping coefficients, respectively, which are determined from the results of other loading tests. The analytical results are obtained by numerical calculation using linear acceleration procedure with time step of 1/100 sec. Fig.6(a) and Fig.6(b) show analytical results, which correspond to exprimental ones of Fig.5(a) and Fig.5(b). It is observed that both displacements and accelerations of analytical results are in good agreement with those of experimental ones. It can be said that the simple linear analysis are effective for evaluating the behavior of the system, and the seismic design by the response spectrum method is applicable to the present isolation floor system.

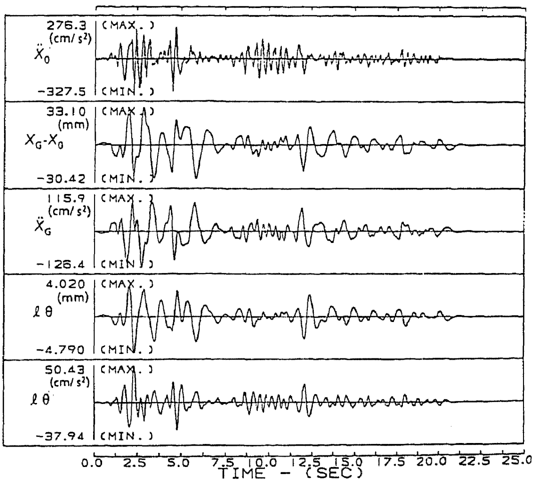


(a) Horizontal Excitation
(Floor Response Wave of El Centro-NS)

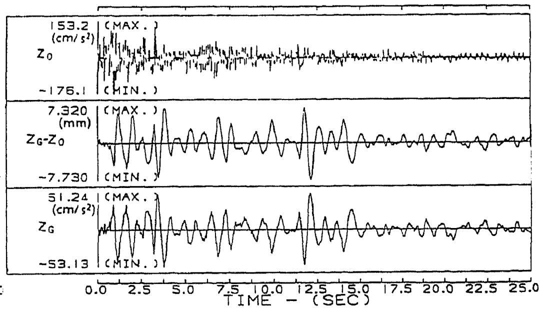


(b) Vertical Excitation
(Floor Response Wave of El Centro-UD)

Fig.5 Experimental Results



(a) Horizontal Excitation
(Floor Response Wave of El Centro-NS)



(b) Vertical Excitation
(Floor Response Wave oF El Centro-UD)

Fig.6 Analytical Results

CONCLUDING REMARKS

The seismic isolation floor system by using 3-dimensional isolator has been developed for high-tech facilities such as computer systems and super-precise equipments. The results of shaking test were satisfactory and the effectiveness of the system was confirmed. The special feature of the system is the introduction of 3-dimensional seismic and micro-tremulous isolation performance, which protect high-tech facilities and machinaries not only from earthquake but also from micro-vibration.

ACKNOWLEDGEMENT

We wish to thank Prof. H. Shibata, University of Tokyo, and Prof. M. Izumi, Tohoku University, for their valuable suggestions and comments. We want to express gratitude also to Prof. M. Kunieda, Meisei Univercity, for his valuable discussion about air spring and dampers. The active supports from the members of IHI Earthquake-Proof Engneering Laboratory, Yokohama Rubber Co.,Ltd. and Advanced Systems Co,Ltd. are also acknowledged.

REFERENCES

1. Kelly, J. M., "Aseismic Base Isolation: A Review.", Proceedings of the Second U.S. National Conference on Earthquake Engineering, Earthquake Engneering Reserch Institute, Stanford, California.
2. Matsuda, T., Aoyagi, S.and Shiomi, S., "Study on Isolation Systems,",Report No.385010, Central Reserch Institute of Electric Power Industries, 1986, (in Japanese)
3. Tokuda. N., Kashiwazaki. A. and Akimoto. M., "Shaking Test of 3-Dimensinal Isolator by Using Air Spring and Rubber Bearing", ASME-PVP Vol.127, 1987, pp421
4. Mastudaira, T. and Kunieda, M., "Vibration Isolation and Damper",in Vibration Engneering Handbook, ed. by Taniguchi, O., Yokendo, Tokyo, 1976, (in Japanese)