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BASE ISOLATION SYSTEM FOR EARTHQUAKE PROTECTION AND VIBRATION ISOLATION OF STRUCTURES

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SUMMARY

A base isolation system for earthquake protection and vibration isolation of structures have been developed and applied to an acoustic/environmental vibration laboratory building. Newly developed laminated rubber bearing and steel rod damper were confirmed by loading test to possess satisfactory performance. Tests and observations before and after the completion of the base isolated building demonstrates that the system can reduce ground born micro tremors by more than 20 dB over 10 Hz, the system is effective even for relatively small earthquakes and the system can restrain the vibration induced by strong winds.

INTRODUCTION

It is required in a wide field to reduce vibrations of structures and it is a keen demand especially in high quality buildings and high technology facilities. It can have effect from the view point of protecting property, preserving operations, increasing productivity, expansion of site locations and so on to reduce vibrations caused not only by earthquakes but also by trafic induced micro tremors and by strong winds.

A base isolation system for structures has been newly developed. This system uses in the isolation floor the laminated rubber bearing and the steel rod damper as its horizontal energy dissipator to give structures adequate vibration properties not only to reduce earthquake response but also to isolate ground born micro tremors and to restrain vibration during strong winds.

An acoustic/environmental vibration laboratory building was constructed in the premise of Kajima Institute of Construction Technology. The tests that will be conducted in this building are very sensitive to micro tremor, so this base isolation system was applied.

This paper describes the design, the verification tests of devices and the tests and observation results on this building.

ISOLATION DESIGN

The cross section of the acoustic/environmental vibration laboratory building is shown in Fig.1 and the arrangement of devices in the isolation floor in Fig.2. The building is supported by 8 laminated rubber bearings of design dead weight of 165 tf and 10 of 100 tf, and 14 steel rod dampers are used. The total weight of the building is about 2,270 tf.

The vertical spring of the isolation floor or the one of rubber bearings was determined so as to have natural frequency of 5 Hz to cut off ground born micro tremor by more than 20 dB on the basis of the data of measurement of micro tremor at the site. Meanwhile, the horizontal restoring force characteristics of the isolation floor can be modeled as bi-linear as shown in Fig.3 when it is assumed that rubber bearing is elastic and steel rod damper is elastic-perfect plastic. Three parameters of elastic stiffness K_1, post yield stiffness K_2 and yield load F in the bi-linear characteristics were determined through the parametric analysis of earthquake response and wind response. The determined values of K_1, K_2 and F are shown in Fig.3. K_1 was determined mainly from the point of view to restrict the acceleration response in the building within 1 Gal against strong wind of 1 year return period except typhoons. K_2 or the lateral spring of rubber bearings correspond to the natural frequency of 0.5 Hz.

VERIFICATION TESTS OF DEVICES

Laminated rubber bearing and steel rod damper were designed to achieve the characteristics of isolation floor determined above. They were manufactured by way of experiments and their verification tests were carried out.

Laminated rubber bearing The laminated rubber bearing of design dead weight of 165 tf is shown in Fig.4. Natural rubber used is of hardness of 40 and shear elastic modulus of 5.6 Kgf/cm^2. Dynamic loading apparatus of rubber bearing is shown in Photo 1. Test results is shown in Fig.5 for the horizontal characteristics and in Fig.6 for the vertical. Both show that the elastic and damping is very small. Horizontal spring corresponds to natural frequency of 0.48 Hz and vertical 4.9 Hz. They agree well with the design values. The test result under large horizontal deformation is shown in Fig.7. The elastic feature is maintained even in such large deformation.

Steel rod damper The steel rod damper is shown in Fig.8. The mild steel used is of yield stress of 2.87 tf/cm^2. Reinforced concrete deformation restrainer is used so that it can protect the steel rod from local damage at the fix end. Dynamic loading apparatus of the Damper is shown in Photo 2. Curvature distribution along the steel rod is shown in Fig.9 compared with that without deformation restrainer. It can be seen that the curvature with deformation restrainer is restricted to the curvature of restrainer and it is distributed in a wide area. The effect of this, the total energy absorption of this damper is about four times as large as that without a restrainer. The test result under constant amplitude to failure is shown in Fig.10. The analytical model of this damper is defined from this result, as shown in the figure.

TEST AND OBSERVATION ON THE BASE ISOLATED BUILDING

The rubber bearings and the steel dampers were installed in the base and the isolation designed building was completed on July 30, 1986. The base isolation devices between the double foundations are shown in Photo 3. Before and after the completion of this building, forced vibration tests and micro tremor measurements were conducted, and the earthquake and wind observations have been continued ever since.

Forced vibration test The forced vibration test was conducted using a vibration exciter mounted on the roof. The natural vibration modes and the natural frequencies of the building are shown in Fig.11. The measured 1st natural frequency is about 1.5 Hz, which is higher than the designed value of 1.2 Hz. This dif-

ference comes from the following reasons:
(1) The weight of the building is about 2000 tf, which is less than the design estimation.
(2) The stiffness of the rubber bearings is higher in the very small deformation.
(3) The slide bearings of the roof and the corridor linked to the next-door building have some friction.

Measurement of micro tremor The vertical acceleration transmissibility from the ground micro tremor to the building was measured. The ground was excited up to 20 Hz with a vibration exciter, and over 20 Hz an impulse hammer was used to put the inpulse to the lower foundation. Acceleration transmissibility to the first floor of the building from the lower foundation is shown in Fig.12. It demonstrates that the transmissibility in the base isolated state is reduced to more than 20 dB (10 times in amplitude) over 10 Hz compared with that in the base fixed state. This result is very satisfactory with the design target level.

Earthquake observation The earthquake observation records of April 10, 1987 and of December 17, 1987 are shown in Fig.13 and Fig.14. The result of simulation analysis is also shown in Fig.14. The analytical model is shown in Fig.15. In this model, the restoring force characteristics of isolation floor is determined from the dynamic loading test results of the rubber bearing and the steel rod damper in the foregoing. And the upper structure is represented by lumped mass system, of which spring is derived from FEM analysis.

Observed results show that this system is effective to reduce acceleration response even against small or moderate earthquakes. And the analysis agrees well with the observed record.

Wind observation The wind observation record of February 25,1987 is shown in Fig.16. The acceleration response was far less than 1 Gal. The recorded wind speed corresponds almost with the same level as the design wind speed. Therefore, this results is quite satisfactory with the design requirements.

CONCLUSION

A base isolation system for earthquake protection and vibration isolation of structures has been newly developed and applied to the acoustic/environmental vibration laboratory building. And the conclusions obtained are as follows:
(1) The loading test result of the newly developed rubber bearing and steel damper shows that they have satisfactory properties.
(2) The acceleration response of the building to the ground born micro vibration satisfies sufficiently the design target.
(3) The earthquake response observation results show that the system is effective even for relatively small earthquakes. And the simulation analysis agrees well with the observed records.
(4) The wind observation record shows the sufficient stability of the building against strong wind.

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3. Lee, D. M. and Medland, I.C., "Base Isolation System for Earthquake Protection of Multi-Story Shear Structures", Earth. Eng. and Str. Dyn., vol. 7, (1979).

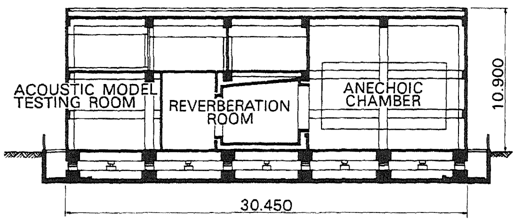


Fig. 1 Cross Section of Acoustic/Environmental Vibration Laboratory Building

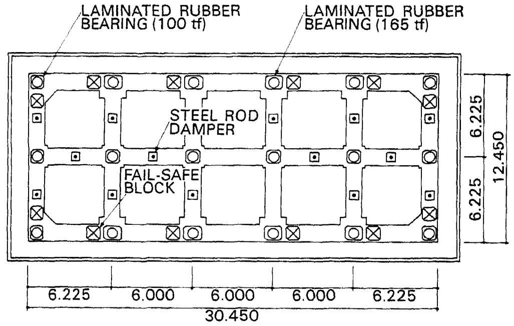


Fig. 2 Arrangement of Devices in Isolation Floor

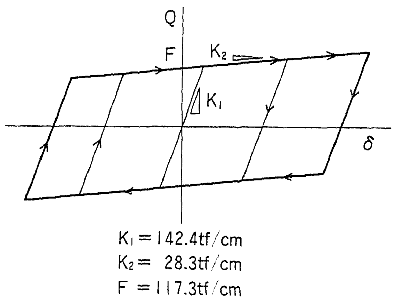


Fig. 3 Bi-linear Model for Isolation Floor

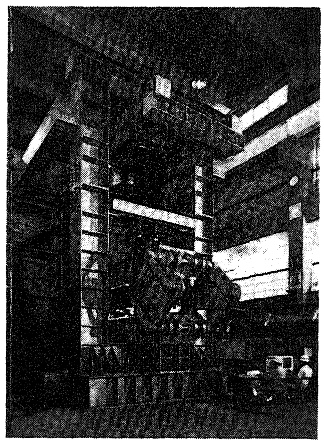


Photo 1 Loading Apparatus of Rubber Bearing

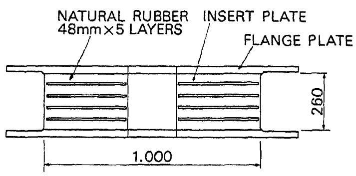


Fig. 4 165 tf Laminated Rubber Bearing

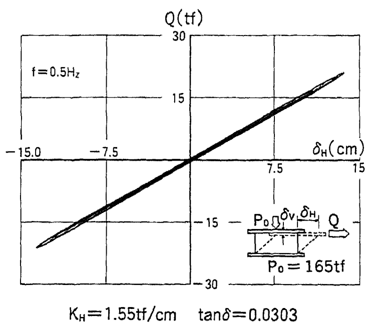


Fig. 5 Horizontal Characteristics of Rubber Bearing

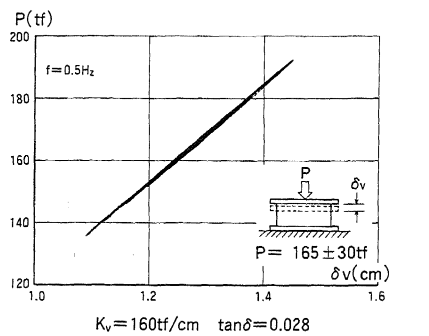


Fig. 6 Vertical Characteristics of Rubber Bearing

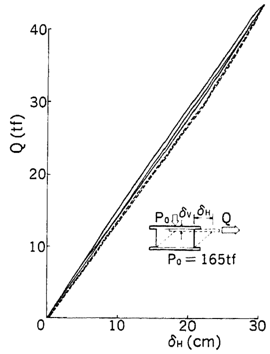


Fig. 7 Characteristics of Rubber Bearing under Large Deformation

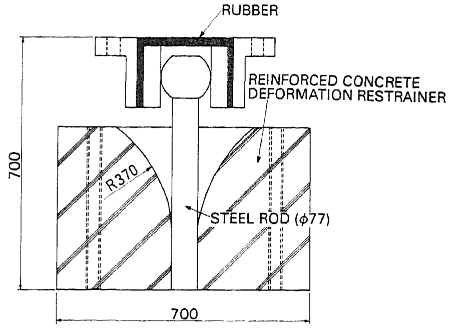


Fig. 8 Steel Rod Damper

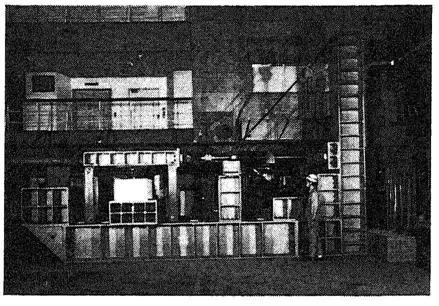


Photo 2 Loading Apparatus of Steel Damper

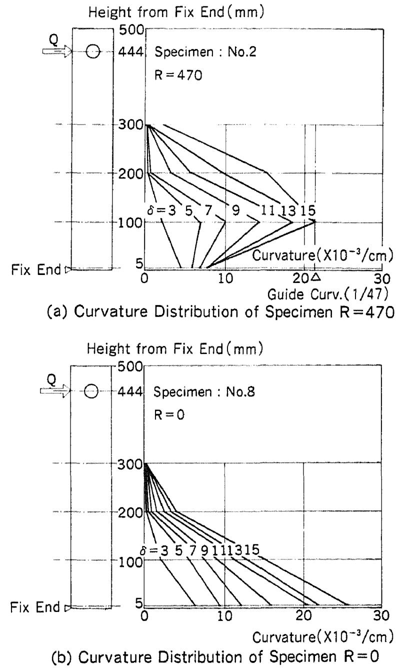


Fig. 9 Curvature Distribution along Steel Rod

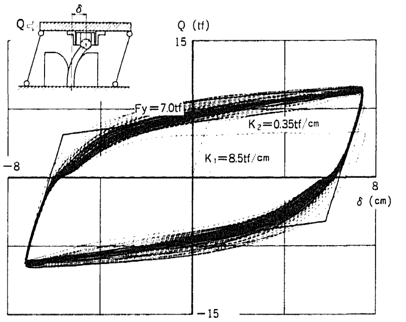


Fig. 10 Restoring Force Characteristics of Steel Damper

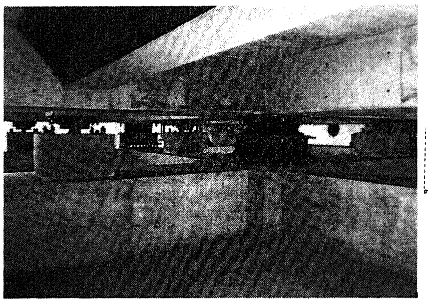


Photo 3 View of Base

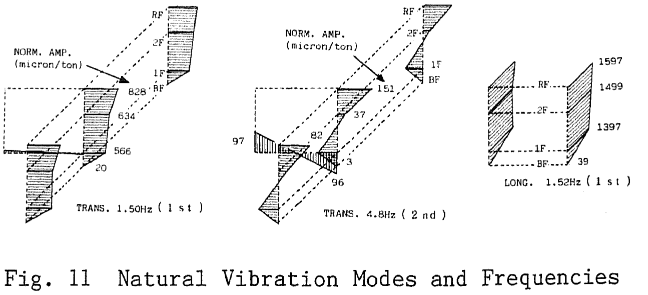


Fig. 11 Natural Vibration Modes and Frequencies

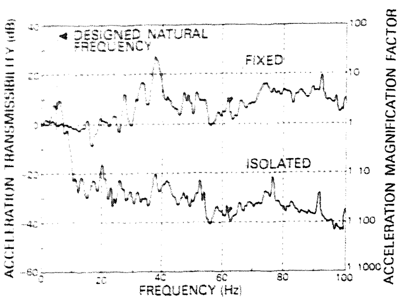


Fig. 12 Vertical Acceleration Transmissibility

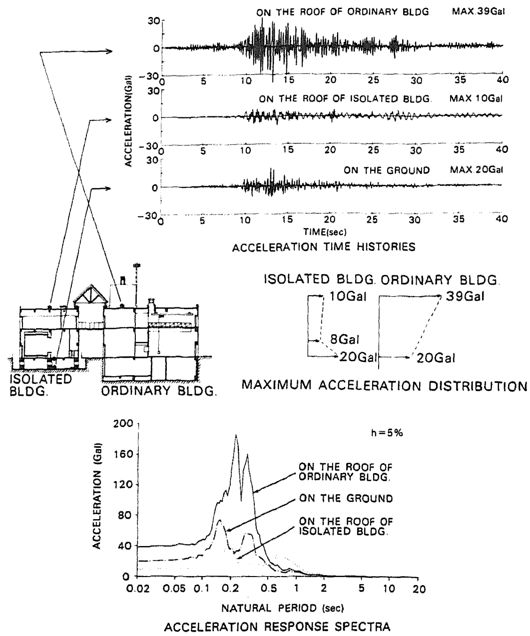
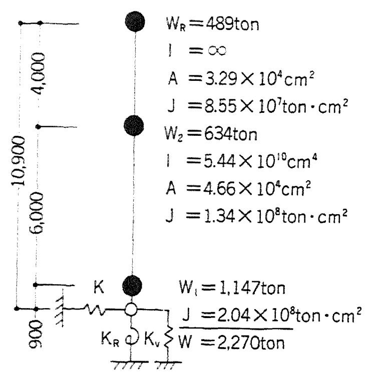


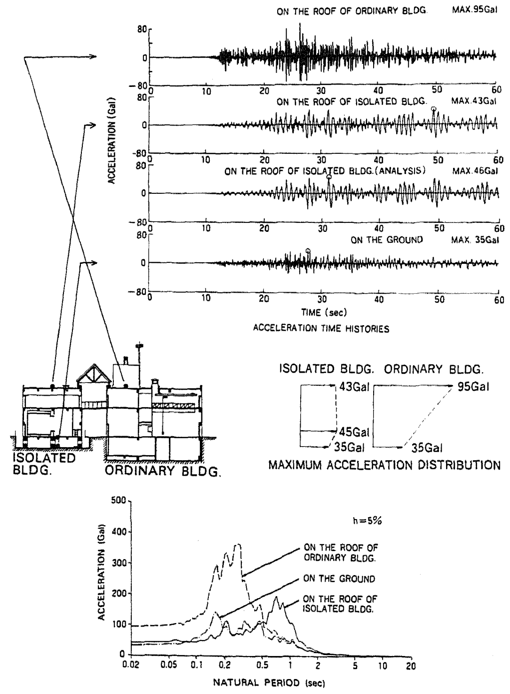
Fig. 13 Earthquake Observation Record of April 10, 1987



Rocking Spring $K_R = 5.64 \times 10^8 tf \cdot cm / rad$

Vertical Spring $K_V = 2348tf/cm(5Hz)$

Fig. 15 Analytical Model



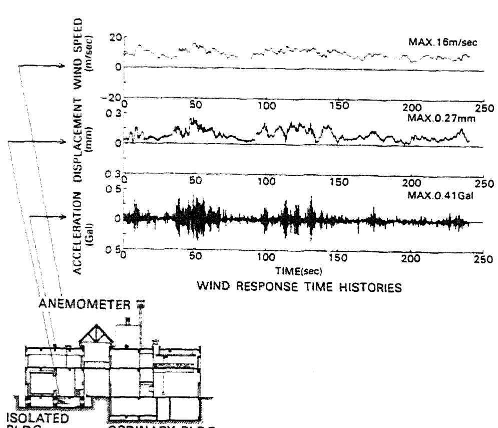


Fig. 16 Wind Observation Record of February 25, 1987

Fig. 14 Earthquake Observation Record of December 17, 1987