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STUDY ON BASE ISOLATION SYSTEM FOR EARTHQUAKE PROTECTION AND VIBRATION ISOLATION BY LAMINATED HIGH-DAMPING RUBBER

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SUMMARY

Application of base isolation is expanded from the frequency range of earthquake motions to the ranges for micro-vibrations, and further, structure-borne noise, and the use of laminated high-damping rubber with the rubber itself possessing substantial damping capability is tried with the aim of isolating these vibrations. This paper reports on the results of various experiments regarding the basic characteristics of laminated rubber, and further, experiments conducted to grasp the vibration characteristics and vibration isolation characteristics of the laminated rubber on application to a full-size structure.

As a result of various tests, it is substantiated that this is an effective system for earthquake protection and vibration isolation, and it is thought possible for application to be made to buildings such as halls, apartment houses, research facilities, etc. constructed near subways and railroads where vibration and structure-borne noise are problems.

INTRODUCTION

The necessity for control of microvibrations and structure-borne noises due to traffic vibrations and machinery and equipment vibrations at semiconductor plants and advanced technology research institutions, or facilities such as concert halls has been increasing in recent years. By structure-borne noise is meant vibration propagated through a solid from the source of vibration which is radiated into the air in the end as sound and is audible, or what is directly transmitted to the human body as vibration and is sensed as noise.

The authers' company has been engaged in research and development on base isolation systems conducting various experiments on the three types of (1) laminated natural rubber plus steel damper system, (2) laminated natural rubber with lead plug system, and (3) laminated high-damping rubber system. The laminated high-damping rubber system is featured by having a stable damping capacity from the very small deformation range to the large deformation range, and is considered to have not only earthquake protection capability, but also favorable properties regarding vibration isolation mainly in the very small deformation range such as to cut off microbivrations and structure-borne noises.

With microvibrations and structure-borne noise it is important to pay attention to vertical motions besides horizontal motions which are considered as main in earthquake motions, and the high-damping rubber system is thought to be effective for vibration isolation regarding vertical motions.

Since this system does not require added dampers, and is excellent in constructability, it is possible for application to be made in a wide range including earthquake protection and vibration isolation of existing structures.

The possibilities of base isolation systems using laminated high-damping rubber are examined in this paper.

CHARACTERISTICS OF LAMINATED HIGH-DAMPING RUBBER

Outline of Laminated High-damping Rubber The design values below were set up with the aim of developing base isolation systems for both the horizontal and vertical directions.

·Horizontal natural frequency; Fh = 0.5Hz, Damping; 10-15%
·Vertical natural frequency; Fv = 5Hz, Damping; approximately 5%

The cross section of laminated high-damping rubber based on this specification is shown in Fig. 1. To support the full-size structure weighing a total of 140 t described in the following section with four laminated rubber pads, the vertical design axial force per pad was made 35 t. The design target stiffness per pad coresponding to the design target value would respectively be 0.352 t/cm at ±40-percent shear deformation in the horizontal direction and 35.2 t/cm at load changing of 30-percent (10.5 t) of design axial force in the vertical direction.

Since vibration isolation in the vertical direction have been considered, thickness of a single rubber layer is large compared with laminated rubber normaly used, while the number of layers is smaller.

Outline of Characteristics Tests Basic tests of characteristics were performed on the abovementioned laminated rubber. The objectives were to ascertain the basic characteristics of laminated high-damping rubber to investigate the correlation with the design target value, and to provide each of the laminated rubber pads with uniform conditioning before installing at the full-size structure.

The following tests were performed on the individual laminated rubber pads.

Firstly, as a quasi-static loading test in the vertical direction, after loading to vertical design axial force of 35 t, a loading amplitude of ±30 percent (±10.5 t) of design axial force was applied in the vertical direction in the form of sine waves of 0.004 Hz frequency.

Next, as a dynamic loading test in the horizontal direction, the incremental deformation amplitude shown in Fig. 2 was applied as forcible vibration at 0.5 Hz frequency in a condition of a constant axial force of 35 t applied in the vertical direction. By applying this standard loading program cycle 10 times per pad, the specimens were provided conditioning along with which the effects of repetitive loading were investigated.

Test Results The load-deformation relation according to vertical loading test results is shown in Fig. 3. Axial force of 35 t was introduced in approximately 5 min, and vibration was applied approximately 5 min later so that the influence of initial creep appeared. The vertical stiffness measured under these testing conditions was approximately 45 t/cm, a value 1.28 times the design target value. The equivalent viscous damping factor was approximately 8 percent and the design target value was amply secured.

The load-deformation relation of horizontal loading test results is shown in Fig. 4. A comparison of the first and third loading program cycles shows somewhat different characteristics. This is a prominent phenomenon of initial conditioning of the laminated high-damping rubber. The restoring force characteristics in the horizontal direction indicate smooth spindle shapes.

The secant stiffness corresponding to deformation amplitude in horizontal loading is shown in Fig. 5, and the equivalent viscous damping factor in Fig. 6. The stiffness depends on the deformation amplitude, with higher stiffness indicated the smaller the amplitude. As for reduction in stiffness due to repetitive loading, this was not very prominent after the first conditioning (first cycle to the second cycle), and was within 5 percent per cycle. Meanwhile, the equivalent viscous damping factor was not swayed very much by deformation amplitude, and a trend of extremely slight decline with decrease in amplitude was indicated at the level of testing deformation used here. It was also learned that there was practically no variation due to repetitive loading either.

In correlation with the design target value, stiffness was 1.2 to 1.4 times the design target value, and the equivalent viscous damping factor exceeded 15 percent, the upper limit of the design target value.

It was confirmed from the abovementioned results that these high-damping rubber pads were slightly different from the design target values but the differences were not as much as to affect base isolation performance.

ASCERTAINMENT OF VIBRATION CHARACTERISTICS IN A FULL-SIZE STRUCTURE

The results of a number of experiments conducted to ascertain the vibration characteristics and vibration isolation capacity of a full-size building when the base isolation system using the laminated high-damping rubber described in the preceding section was applied to the structure are reported here.

Outline of Structure and Experiments The plan and section of the structure are shown in Fig. 7 and a view of laminated high-damping rubber installation in Photo. 1. The structure was a rectangular one-

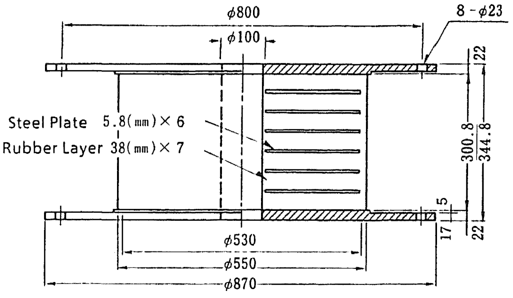


Fig. 1 Cross Section of a Laminated High-damping Rubber

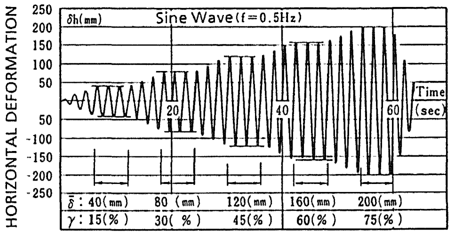


Fig. 2 Loading Program in Horizontal Loading Tests

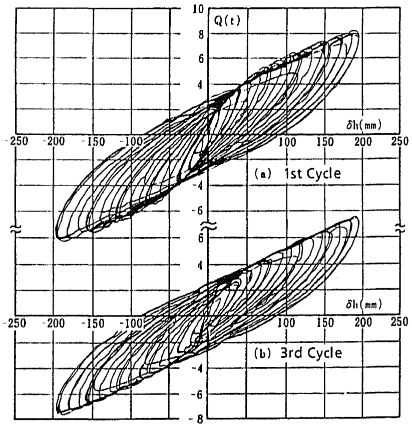


Fig. 4 Load-Deformation Relations in Horizontal Loading Tests

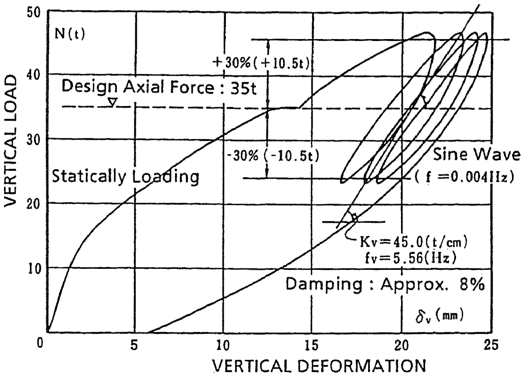


Fig. 3 Test Results in Vertical Loading Tests

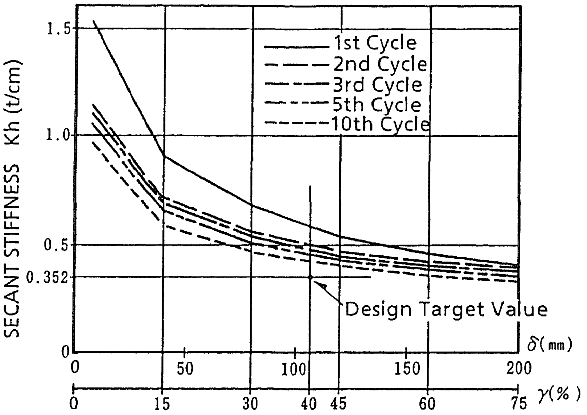


Fig. 5 Secant Stiffness in Horizontal Loading Tests

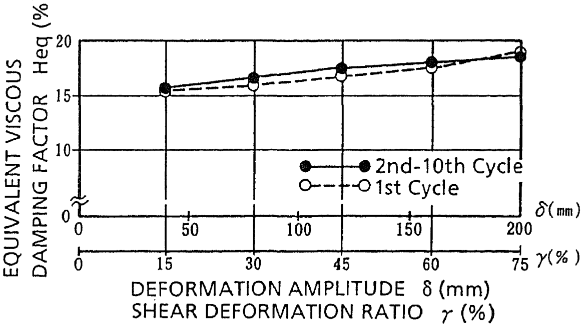


Fig. 6 Equivalent Viscous Damping Factor in Horizontal Loading Tests

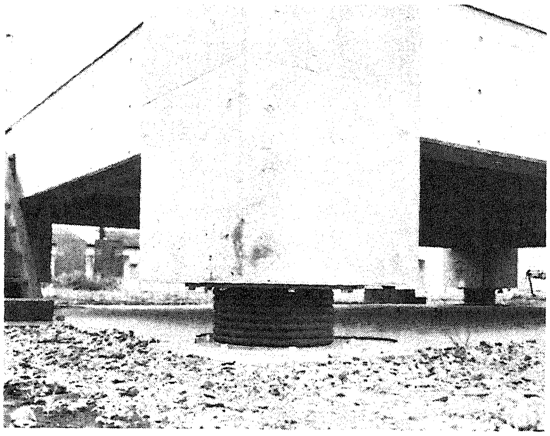


Photo 1　A View of Laminated High-Damping Rubber Installation

Table 1　Natural Frequencies and Damping Factors in Forced Vibration Tests

	Natural Freq.	Damping Factor	Deformation
Horizontal (X)	1.40 Hz	7.15 %	0.113-0.325 mm
Horizontal (Y)	1.44 Hz	7.09 %	0.128-0.350 mm
Vertical	12.9 Hz	9.30 %	approx. 5.3μm

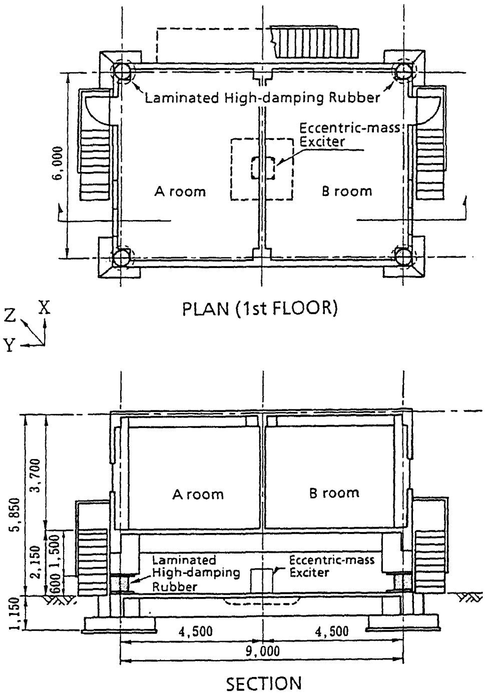


Fig. 7　Plan and Section of the Structure

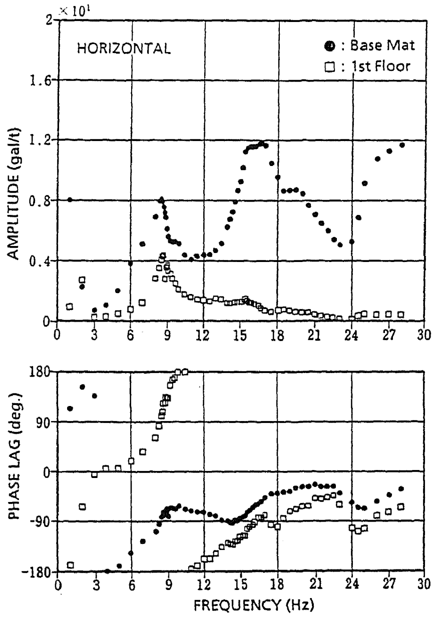


Fig. 8　Resonance Curves in Forced Vibration Tests

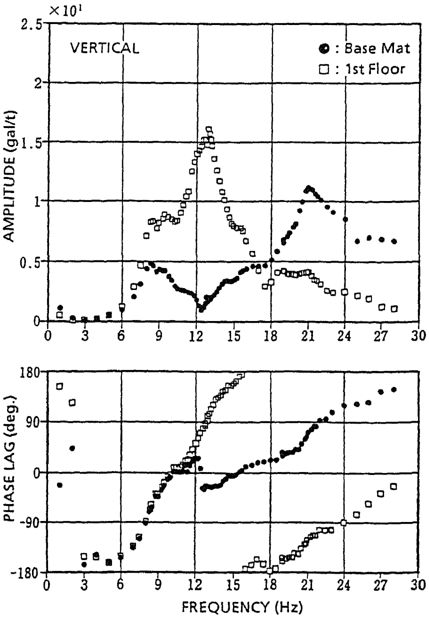


Fig. 9　Resonance Curves in Forced Vibration Tests

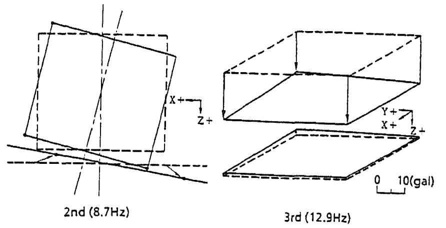
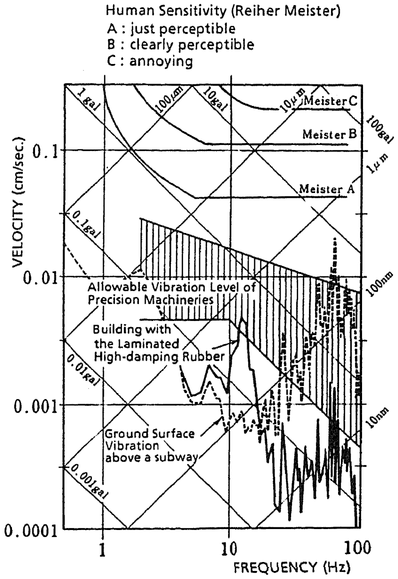


Fig. 10 Mode Diagrams of the Building in Forced Vibration tests



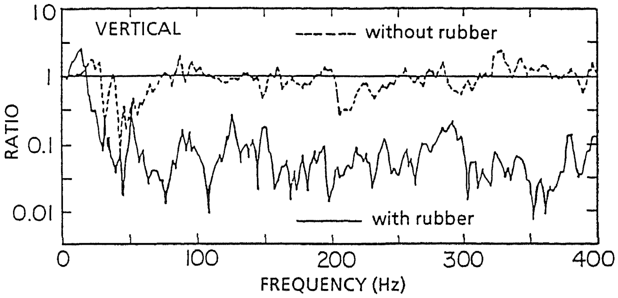


Fig. 11 Transfer Functions (1st Floor / Base Mat)

Fig. 12 An Example of Calculation Assuming a Building above a Subway Structure

story building of height of 5.9 m and plan configulation of 9 m × 6 m. The construction was reinforced concrete, the total weight of building 140 t, and support was provided by four columns.

As vibration sources for grasping the basic vibration characteristics of the buiding at low frequencies below 30 Hz, an eccentric-mass exciter (exciting moment 32 kg·cm) in the vertical direction and both of the exciter and man-induced vibration in the horizontal direction were used.

Further, an electro-hydraulic exciter (exciting force 300 kgf, 20-400Hz) was used as the vibration source for investigating the vibration isolation effect in the high-frequency range. In this experiment, the direction of vibration mainly studied was the vertical in view of the facts that microvibrations which are considered as problems from among environmental vibrations are often larger in the vertical direction rather than the horizontal, and that structure-borne noise radiated from the floor is often large.

The location of exciter installation was the center of the base mat of the building as shown in Fig. 7.

These experiments were conducted for the two stages of non-base-isolated (before installation of laminated rubber with the joints of columns integrated by means of steel plates) and base-isolated (at completion of laminated rubber installation).

Test Results Examples of resonance curves in the low frequency range under conditions of base isolation are shown in Figs. 8 and 9. These curves have been normalized at exciting force of 1 tf. Second and third mode diagrams of the building obtained in this forced vibration test are shown in Fig. 10. The fundamental natural frequencies and damping factors of the building when base-isolated obtained from resonance curves and man-induced vibration are recapitulated and given in Table 1. Calculation of damping factors from resonance curves was done by the half-power method. The maximum deformation is also given in the table.

The fundamental natural frequency was on the high side compared with the design target value assuming a time of gross deformation. This is thought to have been because the deformation in the forced vibration test was smaller than the amount considered at the time of making the earthquake-resistant design.

At test results in the high-frequency range, the transmission ratios of vibrations in the vertical direction above and below the laminated rubber attachment portion according to sweeping vibration are shown in Fig. 11 with the cases of base-isolated and non-base-isolated in superposed position. On looking at this figure, it can be comprehended that there is vibration isolation effect of about 1/10 in the frequency range higher than 30 Hz when base isolation has been provided.

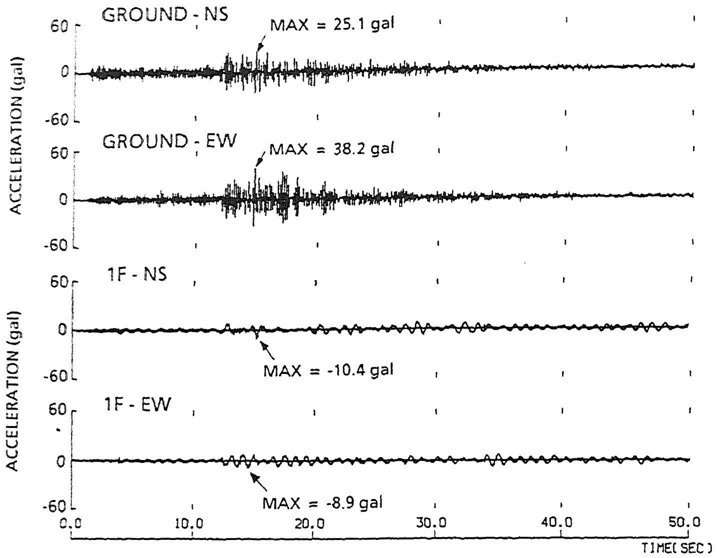


Fig. 13 Observed Earthquake Motions

Example of Calculation Applying Laminated High-damping Rubber to Isolation of Railroad Vibrations

An example of calculation assuming construction of a desirably vibration-free building having this laminated high-damping rubber above a subway structure is given in Fig. 12 as an example of application of this base isolation system. The filtering effect through foundations was ignored in this case, however. The figure shows that in a frequency range lower than about 18 Hz, although the building vibration has been amplified in relation to input vibration, the system using laminated high-damping rubber is effective for vibration isolation in case the allowable vibration level of the precision machinery is at about the upper limit of the allowable range in the figure.

EARTHQUAKE OBSERVATIONS

Earthquake observations are also being made at this building to ascertain the base isolation effects, and a number of earthquakes have already been observed.

Fig. 13 shows the records of an earthquake (magnitude 6.1) observed on March 18, 1988 with its epicenter in eastern Tokyo as an example of an observed earthquake. In this figure, the earthquake motions observed at the ground surface are shown in comparison with the earthquake motions recorded on the first story floor, both for the horizontal direction. It can be seen that in the case of this earthquake the horizontal vibration had been reduced to about 1/3 to 1/4 that at the ground surface.

The earthquake protection performance of the base isolation system using laminated high-damping rubber has been demonstrated through these earthquake observations.

CONCLUSION

In the base isolation system reported here the rubber itself has a considerable damping effect. Consequently, so-called dampers are unnecessary, while the feature is that vertical motions are attenuated more.

During an earthquake, this base isolation system isolates the building proper from the earthquake, while during normal times, it effectively isolates the building from traffic vibrations and machinery and equipment vibrations, and therefore, its use in buildings close to railroads, and further, as severer conditions, buildings and terminals above subways, is considered promising. Since dampers are not required, the space for installation of the system is small, while constructability is excellent, and it is thought possible for the system to be applied to existing buildings also.