Study on Dynamic Characteristics of Elastomer and Viscodamper as Seismic Isolation Device

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ABSTRACT

Various seismic isolation systems have been recently studied to advance the feasibility of Fast Breeder Reactors, especially those of the pool type Fast Breeder Reactor which has a thin cylindrical shell of a large diameter as a reactor vessel. This study was carried out as one of these activities. In this paper, the dynamic characteristics of a laminated rubber bearing (hereafter called elastomer) and a viscodamper are reported and discussed.

1. INTRODUCTION

Recently, seismic isolation systems have become increasingly important. In applying seismic isolation devices to a Fast Breeder Reactor, however, it is necessary to clarify the fundamental characteristics in more detail.

In particular, less studies have been performed on the dynamic behavior of the devices. [1]~[4] So, the dynamic characteristic test for the reduced scale models of the elastomer and the viscodamper was performed, and the difference between the dynamic characteristics of these devices was studied. Furthermore, the effects of the exciting frequency, vertical load, displacement amplitude and the aspect ratio of height/width on the hysteresis loop were also investigated and discussed. As a result, the following items were clarified.

(1) Hysteretic characteristics and shear stiffnesses of these devices under various kinds of excitation condition
(2) Failure modes of the devices in the shearing direction

2. EXPERIMENTS

Figure 1 shows the conceptional illustration of the test apparatus. This test apparatus has various special functions. [1] The outline of the elastomer and the viscodamper used in the tests are shown in Fig.2(a) and 2(b).

In case of the elastomer, four kinds of elastomer were used; i.e., they were different in size and with or without lead plug. Energy dissipation of the viscodamper is achieved when the inner cylinder moves horizontally or vertically through the viscous fluid.

Table 1 (a), (b) show the specifications of these elastomers and the viscodamper. Table 2 shows the test parameters and their values.

The dynamic deformation characteristics, i.e., shear stiffness, dissipated energy, etc., were obtained for various exciting frequencies, displacement amplitudes and vertical loads.

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The horizontal and vertical load applied to the bearing were measured by load cells. The horizontal displacement of the bearing was measured by displacement transducers.
The inertia effect of the moving part of the test apparatus was compensated numerically by a mini-computer.

3. TEST RESULTS FOR ELASTOMER

3-1 Shear stiffness

The relationship between the shear force and the horizontal displacement for two kinds of elastomers, i.e., with lead plug and without lead plug, is shown in Fig.3. [1] The broken line in the figure represents the shear stiffness for the elastomer.
It is known that the shear stiffness for the elastomer with lead plug after yielding is almost the same as that for the elastomer alone.
Figure 5 shows the relationship between the shear stiffness and the vertical pressure. From this figure, it is found that these was no remarkable influence by the vertical pressure through the test. This is an advantage of elastomers in applying them to the design of an Fast Breeder Reactor plant.
Figure 4 shows the relationship between the shear stiffness and the shear strain. From the results of elastomer (C), (D) in this figure, it is found that there is no remarkable influence by the shear strain.
The shear stiffness of elastomer (A: with lead plug), however, has a tendency to decrease with the increase of the shear strain. Thus, it was supposed that the lead plug has the effect of increasing the shear stiffness at low shear strains.

3-2 Dissipated energy

The hysteresis loop for two kinds of elastomers, i.e., with lead plug and without one, is shown in Fig.3. The broken line in the figure represents the shear stiffness for the elastomer only.
As is well-known, the area of the hysteresis loop represents the dissipated energy. Thus it is understood that the dissipated energy for the elastomer with lead plug is much larger than that for the elastomer alone. And because of the large energy dissipation, it is supposed that the elastomer with lead plug has good damping characteristics.

3-3 Failure mode

The failure mode test was carried out by increasing the displacement at a constant velocity in the horizontal direction under constant vertical load.
The horizontal reaction force, the vertical displacement and the vertical load for this test of the elastomer (A) were plotted in Fig.6.
From this figure, it is found that the horizontal reaction force decreases with increase of horizontal displacement, while vertical displacement increases. The decrease in the horizontal load, i.e., the decrease in effective stiffness seems to be caused by the lift-off at the bottom of the elastomer. The lift-off is caused by the fact that the elastomer is fixed to the base plate by dowel pins which cannot transfer the vertical tensile load.
Because of the lift-off, the vertical displacement exceeded the limit of the stroke of the vertical actuator. Therefore, the vertical load suddenly began to decrease and the horizontal load tends to recover slightly.
Figure 7 shows the stability diagram for the overturning. It is found that the maximum horizontal displacement for the overturning tends to decrease with increase of the vertical load. This means that the vertical seismic load reduces the stable region of base isolated structures which employ laminated rubber elastomers with dowel pins as base isolation devices.

In this figure, the critical horizontal displacement from stable to unstable corresponds to the point A where the horizontal load becomes maximum, while the critical displacement from unstable to overturning corresponds to the point B where the horizontal load becomes zero.

A photograph of the lift-off phenomenon is shown in Fig.8.

The relationship between the aspect ratio and the maximum shear strain when the lift-off phenomenon or peeling off occurred in the elastomer is shown in Fig.9.

The plotted point in this figure are the experimental values while the broken line shows analytical values obtained by the following equation, which is derived from the lift-off phenomenon.

$$FH = P(W - \delta) \tag{1}$$

where, F : Shear Load
P : Vertical Load
H : Height of Elastomer
W : Width of Elastomer
δ : Shear Displacement

$$\delta = \frac{PB/H}{(Kr + P/H)} \tag{2}$$

$$Kr = F/\delta \tag{3}$$

In Fig.9, the region above the theoretical curved line represent the unstable region, such as lift-off phenomenon. In the case of the aspect ratio H/W=0.4, the experimental value is in good agreement with the theoretical curved line. For aspect ratio H/W=0.65, however, the experimental critical strain is slightly lower than the theoretical value.

This plotted point was for the elastomer with lead plug. Therefore, it is supposed that the shear stiffness becomes higher because of the installed lead plug and this makes the critical shear strain lower.

In the case of the aspect ratio H/W=0.3, peeling off occurred within the area of the stable region. Generally, critical shear strain in which peeling off occurs is approximately 300%, and the point is beyond this critical shear strain (300%). In this case, turning over will occur at 700% strain. Thus, a criterion of 300% gives safety behavior. Therefore, it is supposed that the elastomer was peeled off before the lift-off occurred.

4. TEST RESULTS FOR VISCODAMPER

4-1 Dissipated energy

Figure 10 illustrates the time history records and hysteresis loops. The loop looks almost elliptic for small displacement, which is ideal viscous damping. The equivalent viscous damping was obtained from the following equation.

$$Ceq = \frac{Wd}{\Pi \omega X^2} \tag{4}$$

where, Ceq : equivalent viscous damping
ω : angular frequency(=2Πf)
f : cyclic frequency
X : dynamic displacement
Wd : dissipated energy

Figure 11 shows the relationship between equivalent viscous damping Ceq at the first cycle and the maximum velocity. In this figure, the equivalent viscous damping is almost constant against the change of the maximum velocity. Also, Ceq does not change for the case where the piston has eccentricity.

Finally, the results mean that the viscodamper could be treated as an ideal viscous damping device and could be mathematically modeled as a damper element which has a constant damping efficient.

Figure 12 illustrates the relationship between the initial temperature of viscous fluid and equivalent viscous damping (Ceq).

In this figure, Ceq of the viscous fluid has a tendency to decrease appreciably as the temperature increases. Therefore, it can be said that Ceq of the viscous fluid has a rather high dependency upon the temperature.

Figure 13 illustrates the relationship between number of cycles and Ceq. The initial temperature for these data were 16.5°C and 28°C. The following are found.

(a) Ceq decreases with increase in the number of cycles.
(b) The decrease of Ceq within the first ten cycles was larger when the viscous fluid initial temperature was lower.
(c) For the beyond the 10th cycle, the effect of the initial temperature of viscous fluid on Ceq was found to be small.

When the number of cycles increased, two phenomena were observed. One is the "sloshing" behavior of the viscous fluid, and the other a local temperature rise adjacent to the moving piston. Therefore, it was thought that these phenomena caused the decrease of Ceq in Fig.13.

5. CONCLUSION

In this paper, the dynamic characteristics, and the failure mode of the elastomer and the viscodamper were studied and discussed. The following conclusions were obtained.

(1) The shear stiffness tends to increase slightly with increase of cyclic frequency.
(2) The shear stiffness of the elastomer does not depend on the vertical pressure.
(3) With increase of shear strain, the shear stiffness of the elastomer with lead plug tends to decrease.
(4) Critical strain for rubber bearing with lead plug will be smaller than that for without lead plug. The maximum horizontal displacement for overturning will decrease with increase of vertical load.
(5) Viscodamper treated here has ideal damping characteristics, and the dependency on the temperature and number of cycles were clarified.

In seismic isolation design, the above results should be taken into consideration.

We hope that these data will contribute to the development of base isolated structures including Fast Breeder Reactors.

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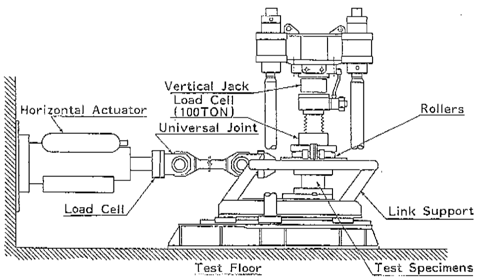

Fig.1 Test Apparatus

Table 1 (b) Specification of Test Viscodamper

	Test Viscodamper
Vertical Height (mm)	240
Diameter (mm)	200
Damping Ratio (%)	10

Table 2 Test Items

Parameters	Conditions
Vertical Pressure	22.2~153 (kgf/cm²)
Cyclic Frequency	~5 (Hz)
Shear Strain	~126 (%)
Cyclic Number	10 and 50

Table 1 (a) Specification of Test Elastomer

	Dimensions			
	Elastomer : A (with lead plug)	Elastomer : B	Elastomer : C	Elastomer : D
Effective width of square bearing (excludes side cover thickness)	228.6 (mm)	←	150	←
Thickness of rubber layer	6.35 (mm)	←	←	←
Total numbers of rubbers	15	←	5	3
The ratio of lead plug area and rubber area	0.0645	—	—	—
Diameter of lead plug	63.5 (mm)	—	—	—
Young's modulus of rubber	2.809 (N / mm²)	←	←	←
Shear modulus of rubber	7.02×10^{-1} (N / mm²)	←	←	←
Aspect Ratio (Height / width)	0.65	←	0.4	0.29

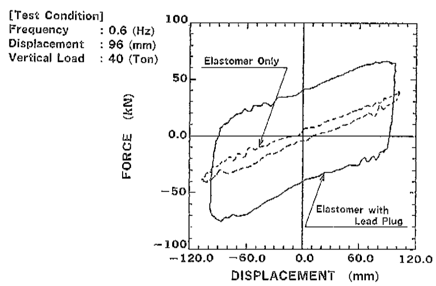

Fig.3 Hysteresis Loop of Elastomer with Lead Plug

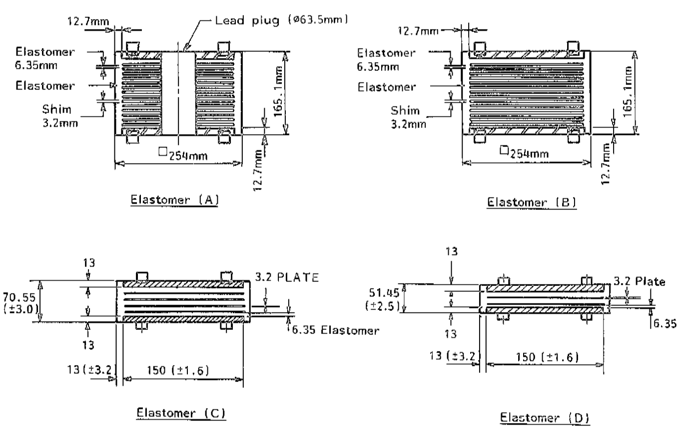

Fig.2 (a) Test Specimens (Laminated Elastomer)

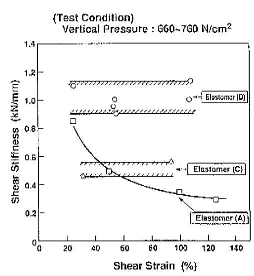

Fig.4 Relationship between Shear Stiffness and Shear Strain

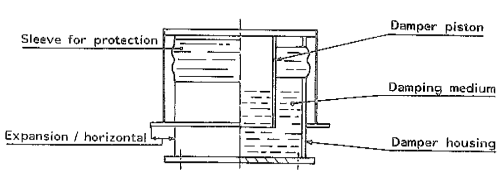

Fig.2 (b) Test Specimen (Viscodamper)

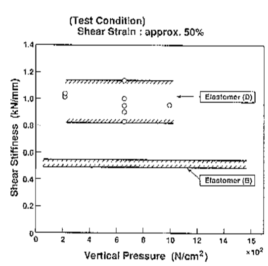

Fig.5 Relationship between Shear Stiffness and Vertical Pressure

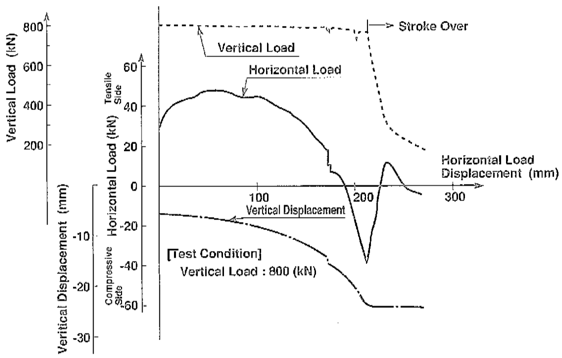

Fig.6 Failure Mode Test

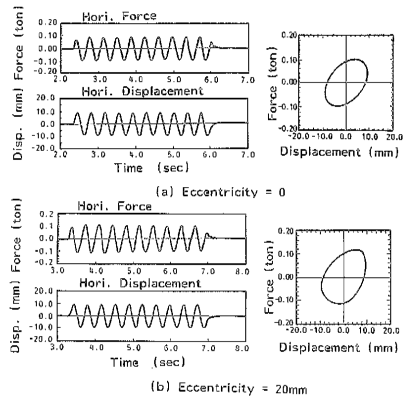

Fig.10 Time History Wave and Hysteresis Loop (Viscodamper)

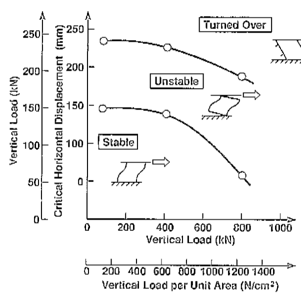

Fig.7 Critical Horizontal Displacement v.s. Vertical Load (Failure Mode Test)

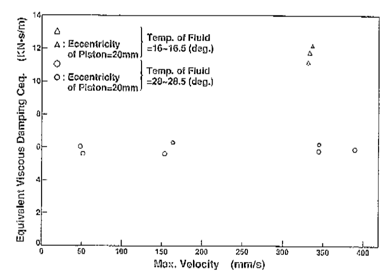

Fig.11 Max Velocity vs. Ceq (Viscodamper)

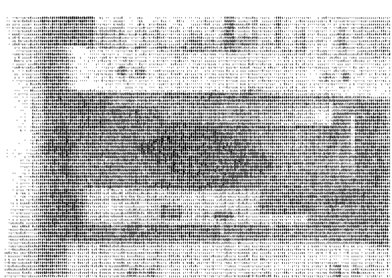

Fig.8 Photo of the lift-off phenomenon

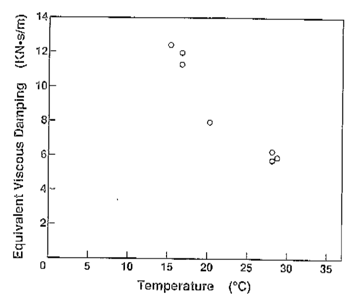

Fig.12 Initial Temp. of Damping Fluid vs. Ceq

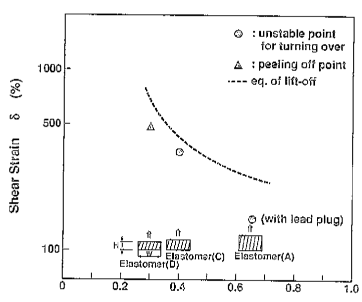

Fig.9 Relationship between aspect ratio and Shear Strain

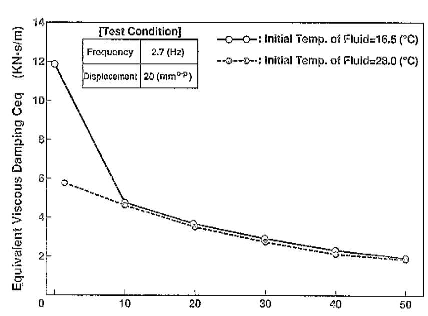

Fig.13 Number of Cycles vs. Ceq (Viscodamper)