Experimental Study on Radiation Resistant Properties of Seismic Isolation Elements

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1. INTRODUCTION

Recently, studies on the application of a seismic isolation system to a reactor building and or the equipment of a nuclear power plant has been carried out. This study aims at investigating the influence which is exerted upon the mechanical properties of the seismic isolation elements by radiation. The authors conducted irradiation tests, using γ rays, on natural rubber bearings (NRB) , lead rubber bearings (LRB) , high damping rubber bearings (HRB) , and the viscous fluid used in viscous dampers. The maximum radiation intensity was 5×10^7R (Roentgen). The comparison between the mechanical properties of each seismic isolation element before and after the irradiation test are reported in the following.

2. OUTLINE OF THE TESTS

2.1 Test Specimens

<u>Laminated Rubber Bearings</u> : The irradiation tests were carried out on four kinds of laminated rubber bearings : NRB , HRB , LRB , into which lead plug is not inserted, and LRB, into which lead plug is inserted. The rubber sheets of the NRB and LRB are made of natural rubber. However, the properties of these rubber sheets are different from each. The shear modulus of the rubber sheet for the NRB is 6kgf/cm^2 and that for the LRB is 8kgf/cm^2. Fig. 1 shows the dimensions of the shape of each piece of laminated rubber bearings.
<u>Rubber Sheets</u> : In order to investigate the radiation resistant properties of the rubber materials, irradiation tests were conducted for the following three kinds of rubber sheets: natural rubber for the NRB , high damping rubber, and covering rubber. After the irradiation tests, three dumbbell test pieces (see Fig. 2) were cut off from each rubber sheet for a tensile test.
<u>Stuck Samples of Rubber Sheet</u> : For the purpose of investigating the properties of the natural rubber for the NRB and high damping rubber for HRB, which is stuck to the steel plates through the use of vulcanization, irradiation tests were conducted for the specimens shown in Fig. 3.
<u>Viscous Fluid</u> : Shear resistance of viscous fluid is utilized for the viscous dampers. Fig. 4 shows the shape of the viscous damper. Radiation resistant properties of two kinds of viscous fluids, silicon and butane compounds, were investigated in this study.

2.2 Irradiation Tests

The irradiation tests for the rubber were made at six levels from 10^4R through 5×10^7R, and for the viscous fluid at five levels from 10^4R through 5×10^6R. In the irradiation tests γ rays from cobalt 60 were used . Table 1 indicates the number of the test specimens at each irradiation level. An entire view of the irradiation test is shown in Photo 1.

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2.3 Mechanical Tests

Measurements of the mechanical properties of each specimen were carried out both before and after the irradiation tests.

Laminated Rubber Bearings : Both the hysteresis loop in a horizontal direction as well as that in a vertical direction were measured. For the measurement of the hysteresis loop in a horizontal direction, an axial force with 5 ton·f (40kgf/cm^2) was loaded and the amplitude of a rubber shear strain $\gamma=\pm 50\%$ and $\gamma=\pm 100\%$ was applied at four cycles each. When measuring the hysteresis loop in a vertical direction, an axial force of 5.0 ± 2.5 ton·f was loaded at four cycles. The stiffness and equivalent damping ratio were calculated through the hysteresis loop, which was obtained from the loading test at the third cycle.

Rubber Sheets : Through the use of the tensile test method referred to as JIS K6301, the following items were measured: stress at a strain level of 50% and 100%, and strength and elongation when the rubber sheets were ruptured.

Stuck Samples of Rubber Sheet In order to measure the strength and elongation at rupture, a shearing test for the stuck samples was conducted at a speed of 50mm/min.

Viscous Fluid : Viscosity of the viscous fluid under three different temperatures, approximately 30°C, 50°C, and 70°C, was measured.

3. TEST RESULTS

Laminated Rubber Bearings : Fig. 5 shows the horizontal stiffness variation ratio of each laminated rubber bearing. The horizontal stiffness of each laminated rubber bearing hardly varies untill the irradiation level reaches 10^6R. However, it gradually increases above 5×10^6R. The increase at 5×10^7R is 20% of the initial stiffness for the NRB, 30% for the LRB and 80% for the HRB. It can be considered that judging from Fig. 5b) and c) the LRB's horizontal stiffness variation, induced by irradiation, was caused by the stiffness variation of the rubber. There is a slight difference in the stiffness variation between the NRB and the LRB without lead plug. This is thought to be caused by the different properties of the rubber materials. Fig.6 shows the variation ratios of the characteristic value Qd of the yield load for the LRB. Irradiation influence is not clearly observed on Qd. Fig. 7 shows the variation of the equivalent damping ratio of the HRB. It begins to decrease gradually above 10^6R, and finally decreases to approximately 50% of the initial value, which was measured before the irradiation test. Fig. 8 indicates the hysteresis loops of the laminated rubber bearings before and after the irradiation tests. In this case, the irradiation intensity is 5×10^7R. As for the NRB and the LRB, a large variation was not observed in the hysteresis loop except in the stiffness. In regard to the HRB, on the other hand, with an increase in the stiffness, the loop area decreased. The aforementioned phenomena in which the damping ratio decreases while the stiffness increases, is caused by the fact that the non-reacted sulphur in the rubber material reacts to the rubber molecules, due to exposure to γ ray generated energy, and accordingly the polymarization of the rubber molecules increases. This is the same phenomena that is found in the deterioration caused by aging.

An influence exerted upon the vertical stiffness of each laminated rubber bearing by the irradiation under 5×10^7R was not observed.

Rubber Sheets : Fig. 9 shows the mechanical property variation ratio of the dumbbell test pieces for natural, high damping, and covering rubber, caused by irradiation. No influence was found upon the dumbbell test pieces under 10^6R. However, the stiffness gradually increased above 10^6R. At 5×10^7R, the increase of the stiffness for the natural and covering rubber was 10~15% of the initial value, and that for the high damping rubber was 70~110%. This tendency corresponds quite well to that which was seen in the results obtained from the tests of the laminated rubber bearings. The rapture elongation and strength of the natural and covering rubber decreased by 10~20% of the initial value. In regard to the high damping rubber, the rapture elongation decreased by 40%, and the rapture strength increased by 40%.

Stuck Samples of Rubber Sheet : Fig. 10 shows the change of the mechanical properties for the stuck samples. The rapture elongation of the natural rubber is almost invariable regardless of the irradiaiton level. However, the rapture elongation of the high damping rubber decreasas with an increase in the irradiation amount. At 5×10^7R, the increase of the rapture strength was 120% of the initial value for the high damping rubber and 30% for the natural rubber.

In this study, a shear failure test of the laminated rubber bearing was not conducted. However, judging from the results obtained from the tests of the dumbbell test pieces and the stuck samples of rubber sheet, it can be estimated that at the rapture, the shear strain and the shear strength for the NRB, only change by approximately 10~20% at the irradiation level of 5×10^7R. On the other hand, in regard to the HRB, it can be considered that the shear strain decreases and the shear strength increases to a large extent.

Viscous Fluid : Fig. 11 explains the viscosity of the silicon and butane compound's viscous fluid at each irradiation level and at each temperature. The viscosity of the silicon compound increased above 5×10^5R and reached approximately 2.5 times the initial value at 10^6R. On the contrary, the viscosity of the butane compound decreased above 10^6R, and at 5×10^6R the decrease was approximately from 30% (at 32°C) to 70% (at 76°C). This is due to the fact that the polymarization of the molecules in the butane compound's viscous fluid progresses through the irradiation of the γ rays, while the molecular linkage in the silicon compound is disconnected.

4. CONCLUSION

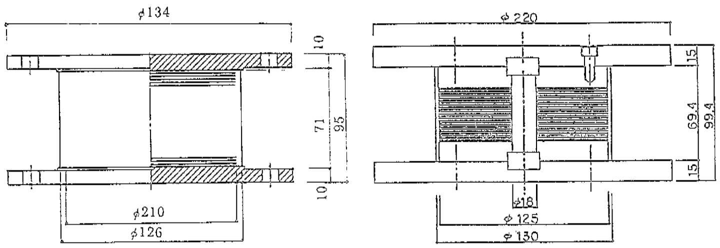
Through conducting the irradiation tests using γ rays on seismic isolation elements , the following results were obtained.

An influence exerted upon the mechanical properties of the NRB, LRB and HRB by the irradeation under 10^6R was not observed. When the accumulated irradiation amount exceeds 10^6R, the horizontal stiffness of these seismic isolation elements increased, and at the same time the equivalent damping ratio of the HRB decreased. At 5×10^7R the increase of the horizontal stiffness was 20% of the initial value for the NRB, 30% for the LRB and 80% for the HRB. The decrease of the equivalent damping ratio of the HRB was 50% of the initial value at 5×10^7R. No variation was observed in the viscosity of the viscous fluid under 10^5R. The viscosity of the silicon compound increased above 10^5R. On the other hand, the viscosity of the butane compound decreased.

Since the accumulated amount of irradiation for the seismic isolation elements, which are applied for the base isolation system to a reactor building, is approximately 10^3R during the period in which they are used, the influence exerted upon these seismic isolation elements by the irradiation can be ignored. However, when they are employed to the equipment, such as a reactor vessel, the variation of mechanical properties of the seismic isolation elements, which is induced by irradiation, must be taken into consideration.

Table - 1 Number of Test Specimen at Each Irradiation Level

Irradiation Level (R)		10^4	10^5	5×10^5	10^6	5×10^6	10^7	5×10^7
Laminated Rubber Bearing	NRB	3	3	—	3	3	3	3
	LRB (without lead plug)	3	3	—	3	3	3	3
	LRB	1	1	—	1	1	1	1
	HRB	3	3	—	3	3	3	3
Rubber Sheet	Natural Rubber for NRB	3	3	—	3	3	3	3
	High Damping Rubber for HRB	3	3	—	3	3	3	3
	Covering Rubber	3	3	—	3	3	3	3
Stuck Sample	Natural Rubber	3	3	—	3	3	2	3
	High Damping Rubber	3	3	—	3	3	2	3
Viscous Fluid	Silicon Compound	1	1	1	1	1	—	—
	Butane Compound	1	1	1	1	1	—	—



Rubber 1.5mm×31=46.5mm
Steel 0.8mm×30=24.0mm

a) Natural Rubber Bearing and High Damping Rubber Bearing

Rubber 1.0mm×25=25.0mm
Steel 0.6mm×24=14.4mm

b) Lead Rubber Bearing

Fig. 1 Laminated Rubber Bearing

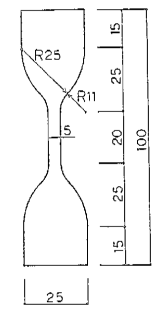


Fig. 2 Dumbbell Test Piece for Rubber Sheet

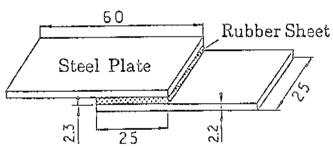


Fig. 3 Stuck Sample of Rubber Sheet

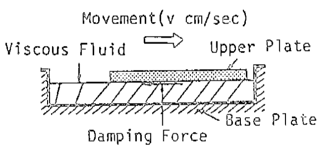


Fig. 4 Viscous Damper

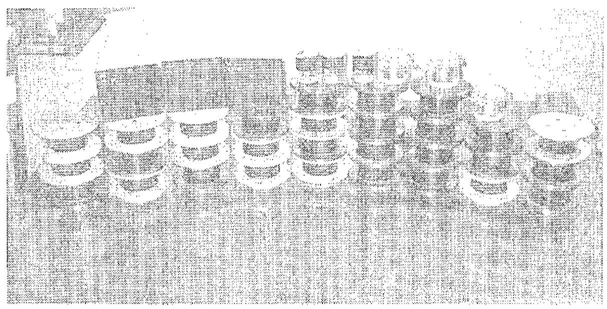
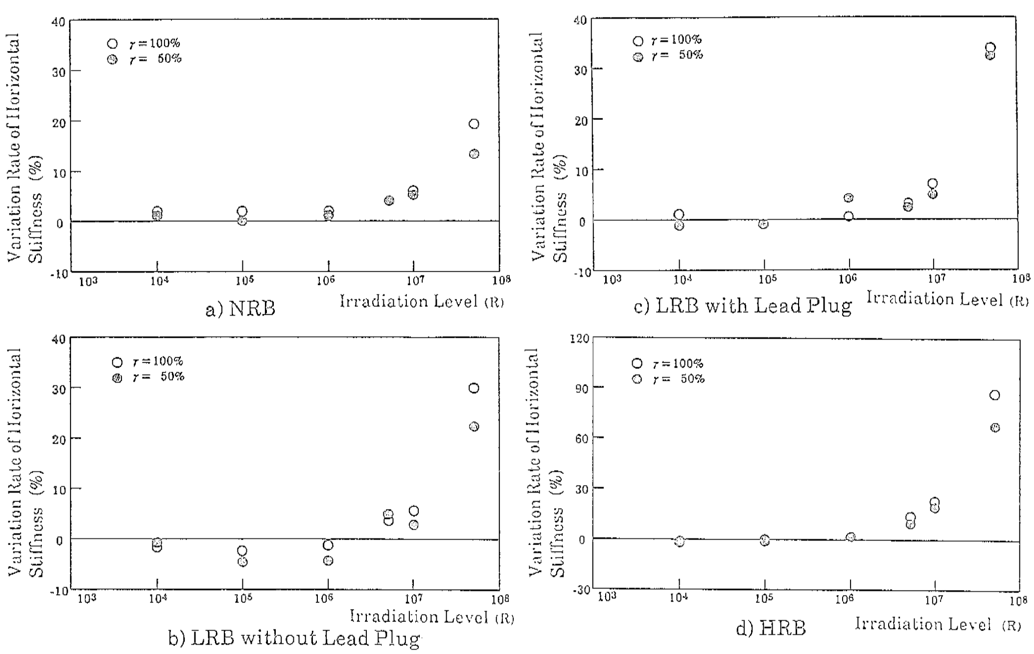


Photo 1 An Entire View of the Irradiation Test



a) NRB

c) LRB with Lead Plug

b) LRB without Lead Plug

d) HRB

Fig. 5 Relationship between Horizontal Stiffness and Irradiation Level (Laminated Rubber Bearing)

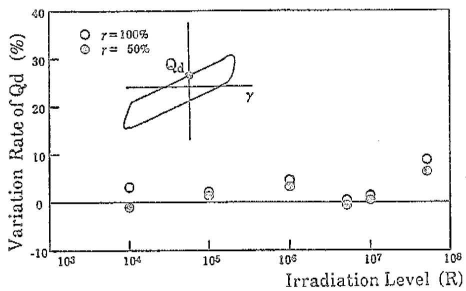


Fig. 6 Relationship between Q_d and Irradiation Level(LRB)

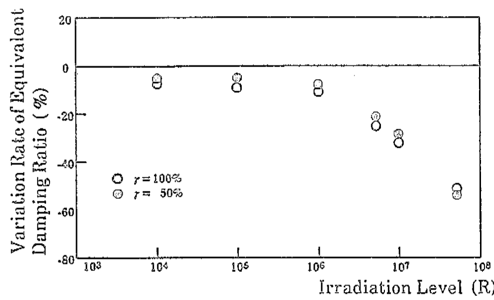
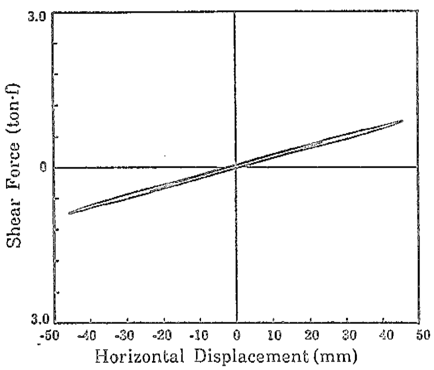
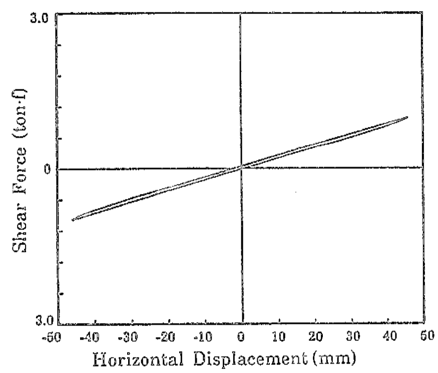


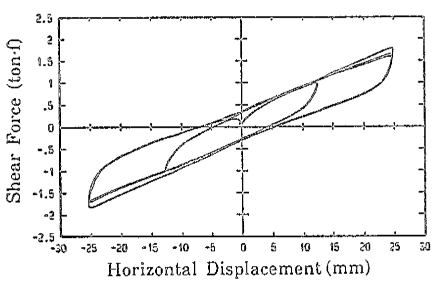
Fig. 7 Relationship between Equivalent Damping Ratio and Irradiation Level



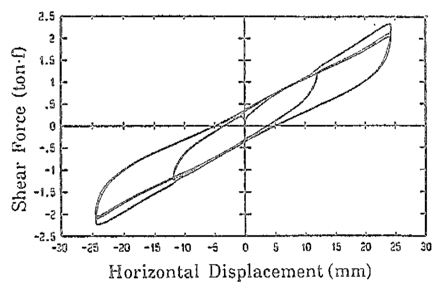
a) NRB before Irradiation



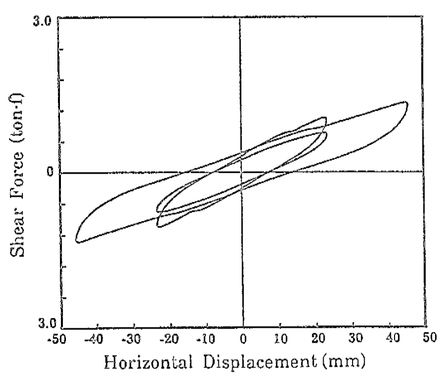
b) NRB after Irradiation of 5×10^7 R



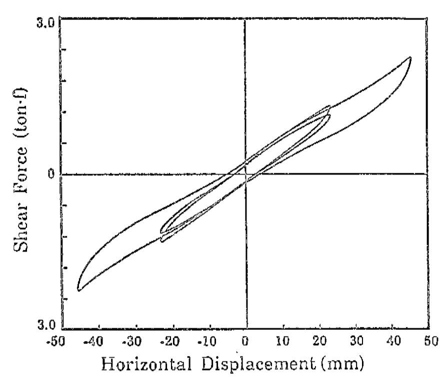
c) LRB before Irradiation



d) LRB after Irradiation of 5×10^7 R



e) HRB before Irradiation



f) HRB after Irradiation of 5×10^7 R

Fig. 8 Hysteresis Loop in Horizontal Direction

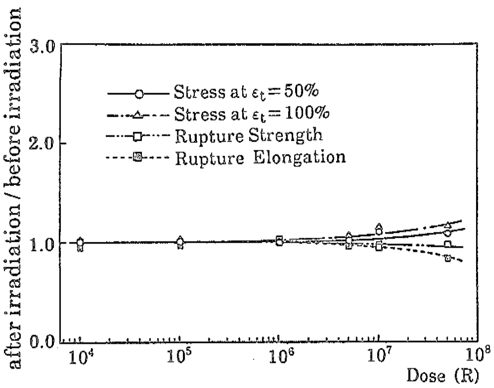


Fig. 9 (a) Mechanical Properties of Natural Rubber Sheet

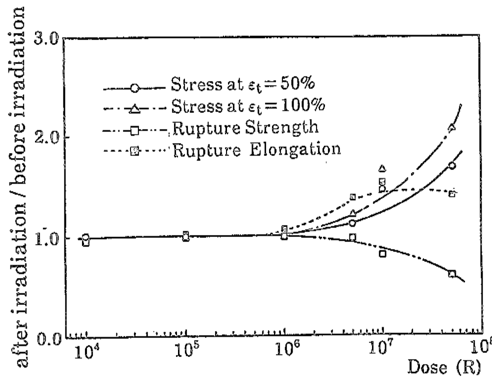


Fig. 9 (b) Mechanical Properties of High Damping Rubber Sheet

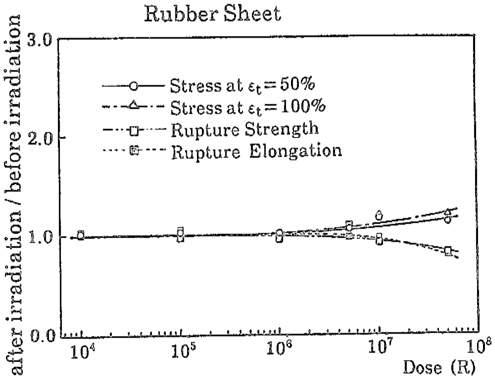


Fig. 9 (c) Mechanical Properties of Covering Rubber Sheet

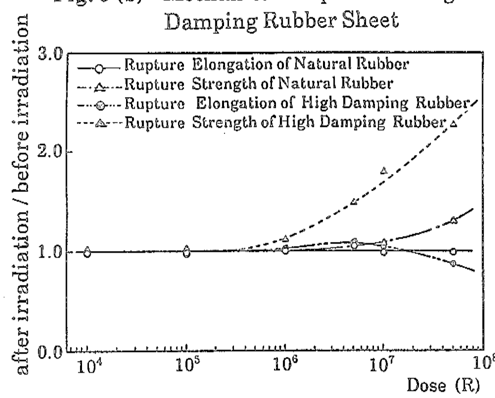
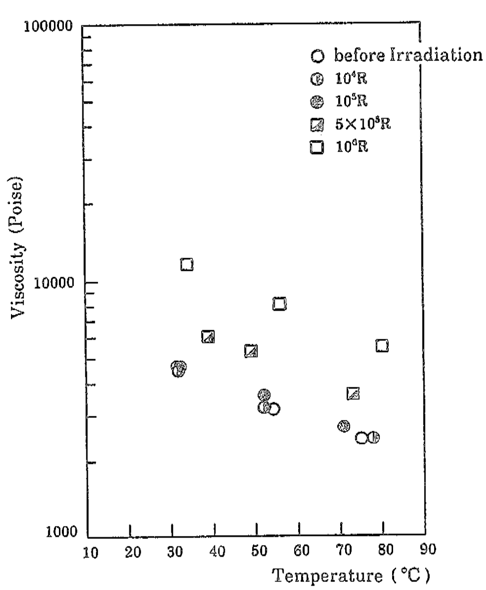
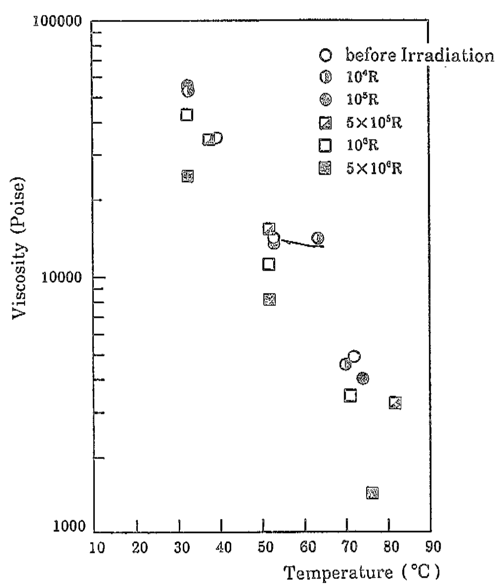


Fig. 10 Mechanical Properties of Stuck Sample



a) Silicon Compound



b) Butane Compound

Fig. 11 Relationship between Viscosity and Irradiation Level