Test on Large-Scale Seismic Isolation Elements
Part 2 Static Characteristics of Laminated Rubber Bearing Type

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ABSTRACT

Seismic isolation test program of CRIEPI to apply seismic isolation to Fast Breeder Reactor(FBR) plant was started in 1987. In this test program,demonstration test of seismic isolation elements was considered as one of the most important research items. Facilities for testing seismic isolation elements were built in Abiko Research Laboratory of CRIEPI. Various tests of large-scale seismic isolation elements were conducted up to this day. Many important test data to develop design technical guidelines was obtained.

1 INTRODUCTION

Seismic isolation is expected to be effective in reducing seismic load,and in raising the reliability of important structure or equipment. Seismic isolation has been already applied to several buildings in Japan. Many experiment and analysis reports were published in several societies, and the characteristics of seismic isolation system and elements was become clear to a certain extent. But, in the application of seismic isolation system to FBR plant, it is one of the most important items in design to estimate the characteristics of elements accurately. So, we conducted static tests of full-scale models under design loading condition,and ones of reduced scale models under over design loading condition. A part of the test results in the present investigation has already been reported in the previous number. The present report is concerned with the test results of lead-rubber bearings(LRB) and high damping rubber bearings(HRB).

2 TEST SPECIMENS AND TEST FACILITY

One full-scale model and two reduced scale models were prepared for the test specimens in both LRB and HRB. Table 1 shows the design specification of the both full-scale models and Fig. 1 shows the detail of the specimens.
A test facility for the static test of laminated rubber bearing was built in Abiko research laboratory. The facility is capable to apply design load to full-scale models and to break reduced scale models. Fig 2 shows the outline of the facility.

3 TEST METHODS

3.1 Horizontal Test

The tests were performed under the condition of low frequency cyclic loading. (under 0.01Hz) Four cycles of sinusoidal displacement were applied horizontally to the every specimens under constant vertical load P. The amplitude of displacement was varied from ±25% to ±200% in shear strain of rubber. And the constant vertical load P which was kept constant during each test was varied from +20%(tension) to -200%(compression) of design vertical load P_o among the test, and the records of the third cycle were adopted as the data to evaluate the characteristics.

3.2 Vertical Test

Four cycles of sinusoidal load was applied vertically to every specimen with offset horizontal displacement and offset vertical load P. The amplitude of sinusoidal load was ±50% of design vertical load P_o. The offset displacement was varied from 0% to 200% in shear strain of rubber, and the offset vertical load was varied from 50% to 150% of design vertical load P_o. After these tests, vertical load was applied up to 200% of design vertical load P0 in each offset displacement.

3.3 Ultimate Test

At first, four cycles of sinusoidal displacement was applied horizontally to reduced scale models under design vertical load P_o. The amplitudes of displacement were ±300% and ±400% in shear strain of rubber. After that, horizontal displacement was applied under design vertical load P0 up to break. In addition to these tests, horizontal breaking tests under various vertical load and vertical breaking tests with some offset displacement were conducted using only LRB. The vertical load P was varied from +100%(tension) to -1000%(compression), and the offset displacement were 0% and 200% in shear strain of rubber.

4. TEST RESULTS

4.1 Horizontal Test

Fig. 3 shows the horizontal hysteresis curve of both full-scale models under design loading condition. Fig. 4 shows the definition of characteristics in horizontal direction. Horizontal hysteresis curve of LRB can be well approximated by a bi-linear irrespective of shear strain level, whereas, horizontal hysteresis curve of HRB has remarkable dependency on shear strain of rubber. Fig. 5 shows the relationship between normalized horizontal spring constant K_H and shear strain of rubber γ, Fig. 6 shows the relationship between horizontal equivalent damping ratio h_H and γ, and Fig. 7 shows the relationship between normalized characteristics dissipator shear strength and γ. Horizontal spring constant K_H of LRB depends on γ, and decrease as shear strain of rubber increase, but horizontal equivalent damping ratio h_H of LRB decreases from 15% to 5% as γ increases, this tendency is generally evident in bi-linear characteristics. The damping ratio increase as vertical load P increases, but characteristics dissipator shear strength Q_d of LRB increases as γ and vertical load increase. K_H of HRB decreases as γ increases, and changes corresponding to experienced maximum shear strain of rubber before. h_H of HRB is about 15% and almost constant irrespective of shear strain level, and Q_d of HRB increases as γ increases.

4.2 Vertical Test

Fig. 8 shows the vertical load versus vertical displacement curve. Fig. 9 shows the relationship between normalized vertical spring constant and offset shear strain of rubber γ_o, And Fig. 10 shows the relationship between vertical equivalent damping ratio h_V and γ_o. Both bearings behave almost linear as shown in Fig. 8, and it was proved that vertical spring constant KV of both bearings agree approximately with the design value when there is no offset shear strain of rubber. However, K_v of both bearings decrease as γ_o increases. h_v of LRB is between 2% and 5%, and h_v of HRB is between 5% and 7%.

4.3 Ultimate Test

Fig. 11 shows the horizontal hysteresis curve of both reduced scale models under design and over design loading condition. As the test results show, the effect of hardening appears clearly at shear strain of rubber above 300%. Fig. 12 shows the relationship between shear stress of rubber τ and shear strain of rubber γ under design vertical load P_o up to break. Horizontal stiffness of each models become larger as shear strain of rubber above 300%. The fracture characteristics of two size of reduced scale models in both bearings agree well. Consequently, the validity of similarity law was confirmed. The fracture characteristics of natural rubber bearing tested before and LRB are similar to each other, the effect caused by lead plug isn't recognized. The fracture characteristics of HRB is a little different from LRB, the tendency of softening was recognized near breaking point. Fig. 13 shows the relationship between τ and γ under varied vertical load in LRB. Characteristics of restoring force up to break is almost uniform within the range of this vertical load. Fig. 14 shows the relationship between tensile stress σ and tensile strain ε up to break in LRB. As the test results show, vertical stiffness in the range of tension become softer as tensile stress of rubber exceeds about 20kgf/cm^2 Fig.15 shows shear strain of horizontal breaking point under varied compressive or tensile stress σ. Fig. 16 shows tensile strain of vertical breaking point under offset shear strain of rubber γ_o. The dependency on compressive or tensile stress in horizontal breaking point are hardly recognized. In these loading condition, deformation capacity of LRB is not influenced by vertical stress.

5 CONCLUSION

The test results may be summarized as follows.

1) Static characteristics of full-scale LRB and HRB under varied loading condition were made clear. These characteristics agreed approximately with the ones calculated by design formulas.
2) Fracture characteristics of reduced scale LRB and HRB models under design vertical load were clarified, and validity of similarity law was confirmed.
3) Fracture characteristics of reduced scale LRB model under varied vertical load was clarified.

ACKNOWLEDGEMENTS

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REFERENCES

1. Mazda,T.,Shiojiri,H.,Oka,Y.,Fujita,T.,Seki,M.(1989).Test on Large-Scale Seismic Isolation Elements.SMiRT10,Vol.K2,pp679-684
2. Mazda,T.,Oka,Y.,Fujita,T.(1990).Test on Seismic Isolation Elements for FBR.International Fast Reactor Safety Meeting,Vol.III,pp413-pp422

TABLE 1

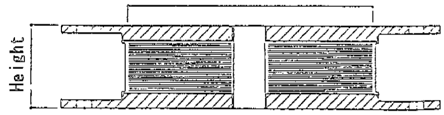
Design Specifications of both full-scale models

Parameter \ Type		LRB	HRB
Loading Weight Po(tonf)		500	500
Natural Freq. (H_z)	Hor. fH	0.5	0.5
	Vert. fv	20	20
Spring Const. (tonf/cm)	Hor. KH	5.04*	5.04** (4.26)***
	Vert. KV	8057	8057
Horizontal Disp. (cm)	Linear	50	50
	Breaking	100	100
Characteristics Dossipator Shear Strenth Qd (tonf)		21*	52** (31)***

* Shear strain of rubber 112.5%

** Shear strain of rubber 100%(Dynamic)

*** Shear strain of rubber 100%(Static)

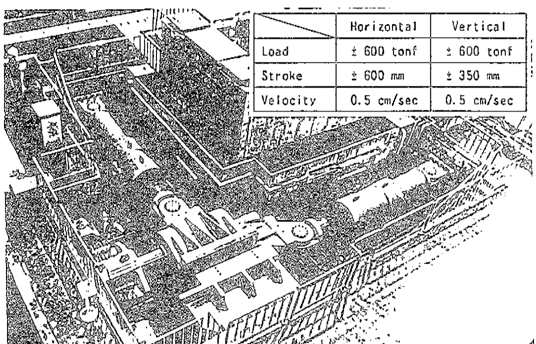


Parameter \ Type	LRB	HRB
Diameter (mm)	1600	1420
Height (mm)	580	620
Thickness of Rubber Sheet (mm)	9	8
No. of Rubber Sheet	25	31
Thickness of Steel Plate (mm)	5.8	5.8
No. of Steel Plate	24	30
Hardness Degree of Rubber	40	60

LRB: Lead Rubber Bearing

HRB: High damping Rubber Bearing

Fig. 1 Details of laminated rubber bearing



	Horizontal	Vertical
Load	± 600 tonf	± 600 tonf
Stroke	± 600 mm	± 350 mm
Velocity	0.5 cm/sec	0.5 cm/sec

Fig.2 Outline of Facility

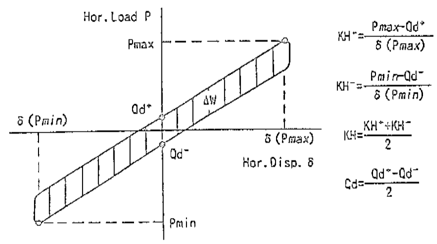


Fig.4 Definition of Characteristics

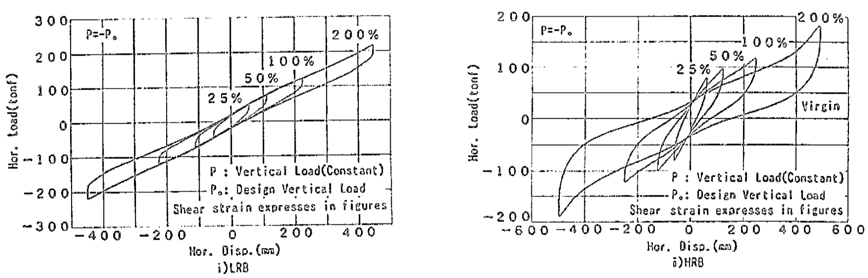


Fig.3 Horizontal Hysteresis Curve of Both Full-Scale Models

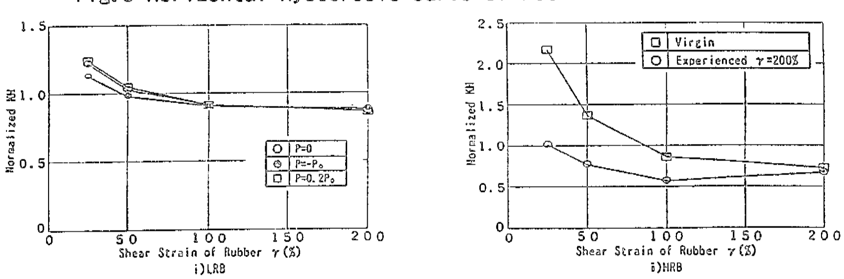


Fig.5 Relationship between Normalized kH and Shear Strain of Rubber γ

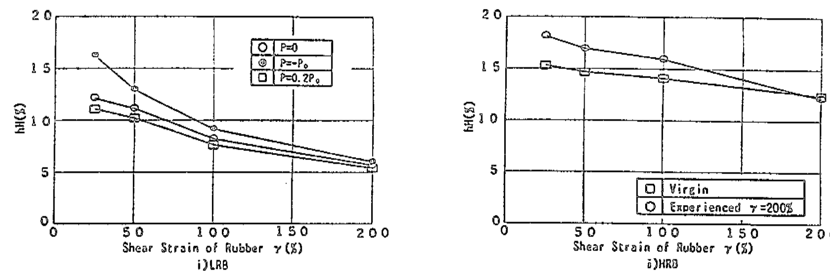


Fig.6 Relationship between Eq. Damping Ratio hH and Shear Strain of Rubber γ

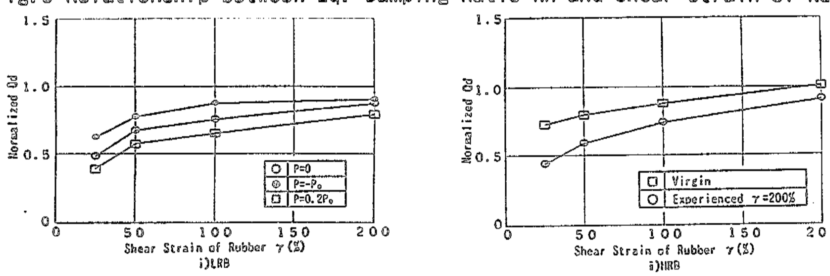


Fig.7 Relationship between Normalized Qd and Shear Strain of Rubber γ

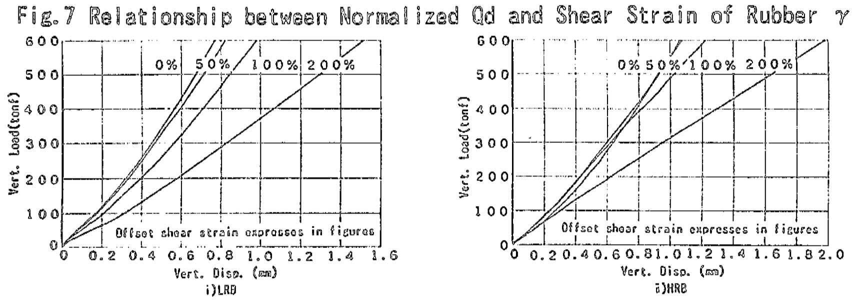


Fig.8 Relationship between Vert. Load and Vert. Disp. of Both Full-Scale Models

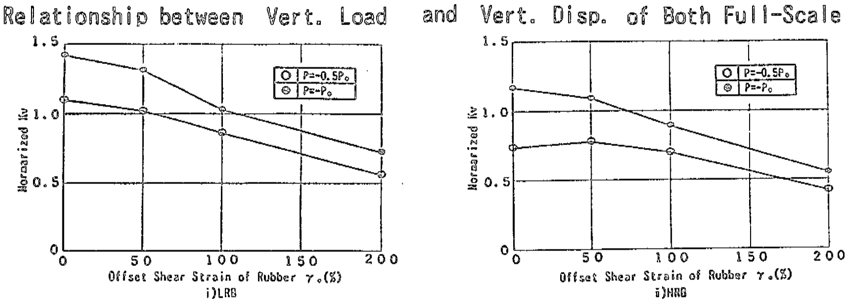


Fig.9 Relationship between Normalized Kv and Offset Shear Strain of Rubber γ_o

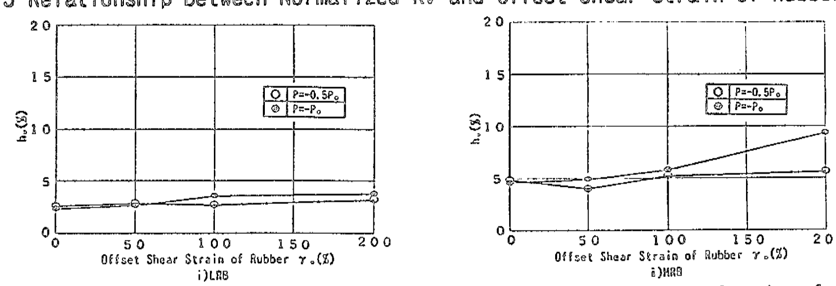


Fig.10 Relationship between Eq. Damping Ratio hv and Offset Shear Strain of Rubber γ_o

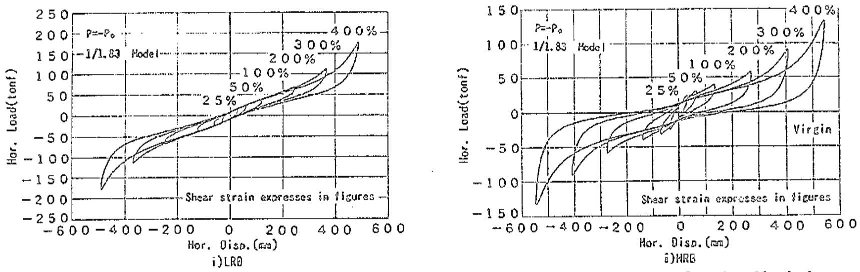


Fig. 11 Horizontal Hysteresis Curve of Both Reduced Scale Models

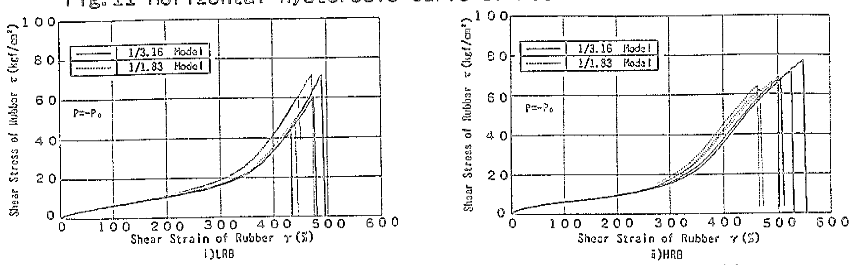


Fig. 12 Relationship between Shear Stress τ and Shear Strain of Rubber γ up to Break

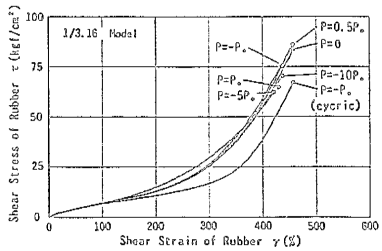


Fig. 13 Relationship between Shear Stress τ and Shear Strain of Rubber γ under Varied Vertical Load P

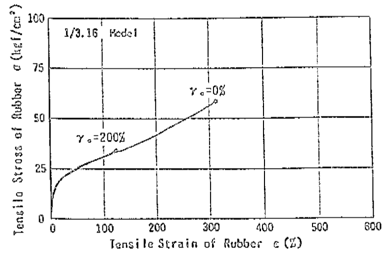


Fig. 14 Relationship between Tensile Stress σ and Tensile Strain ε up to Break

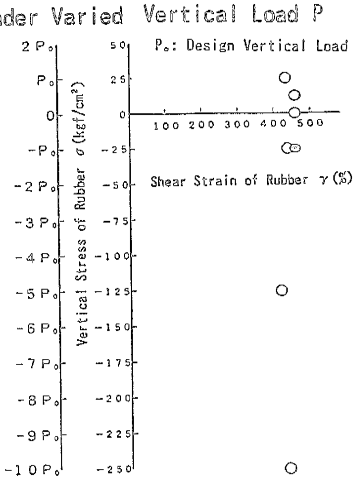


Fig. 15 Shear Strain of Rubber γ in Horizontal Breaking Point under Varied vertical stress σ

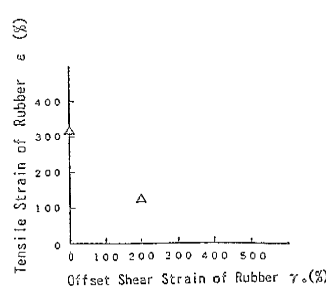


Fig. 16 Tensile Strain of Rubber ε in Vertical Breaking Point Offset Shear Strain γ_0