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Shaking Table Tests on Laminated Rubber Bearing with High Axial Stress for DFBR in Japan

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ABSTRACT

In the dynamic property which has been developed in the demonstration FBR(DFBR)[1] incorporating seismic base isolation in Japan, the initial horizontal natural period is 1.0 second, the isolated natural period is 2.0 seconds and the axial stress of a laminated rubber bearing(RB) is 25 kgf/cm^2.We try to develop an RB whose material is the same as ordinary RB , but the axial stress is 50kgf/cm^2. In this study, to confirm seismic safety of an FBR plant which is isolated by an RB with a high axial stress, shaking table tests are performed. Though the isolated natural period becomes long with a high axial stress, it is confirmed that integrity for seismic isolation devices and building and equipment and piping is ensured. Adopting an RB with high axial stress is effective means to reduce the plant construction cost.

1. OUTLINE OF THE TESTS

a. Test cases

Test cases are shown in Table 1. Test parameters are an isolated natural period and initial natural period of an isolation device. The isolated natural period of 2.0, 2.8 and 4.0 seconds corresponding to a prototype are set up in an RB. As an initial natural period, 1.0 second and a half of an isolated natural period are assumed. As a ratio of an yield force to supporting load in an RB, 0.1 is assumed.

b. Similarity law

The scale ratio of the model to a prototype is 1/15.3, and both acceleration and stress are equal to those of a prototype. The similarity law is shown in Table 2.

c. Superstructure

The experiment model represents the dynamic characteristics of the demonstrated FBR reactor building in Japan. The superstructure is consists of three story steel frame and the gravity center is located on the second story as the same as the prototype. The outline of experiment model is shown in Fig.1. Sloshing models which represent the reactor vessel are set on the second story and the shaking table to grasp the effect to the sloshing response of the high axial stress which make the isolated natural period long. The natural period of sloshing is 4.0 seconds corespondig to the prototype.The scale of length in the sloshing vessel model is the same as the superstructure.

d. Laminated rubber bearings

As a isolation device, three kinds of RBs, i.e. natural rubber bearings with steel dampers(NRB+SD), lead rubber bearings(LRB) and high damping rubber bearings(HRB) are used in these tests.The natural period of 2.0, 2.8 and 4.0 seconds are set up in RBs. The diameter of the RB is about 10 cm.

The steel damper is designed as cantilever beam type with a fixed base and free rotational support by a spherical bearing. The steel damper has an uniform section and the number, diameter, length of the steel damper are designed according to the test parameter. The outline of these RB is shown in Fig. 2(b)

e. Input motion

The maximum probable earthquake ground motion in this study (S2-M)[1)] whose response velocity spectrum with 5 % damping in long periods from 2 seconds to about 10 seconds is 200 kine is used as an input motion to a shaking table test. Each RB is designed to have a margin against a hardening point in a deformation by this input motion S2-M. Three input motions whose spectra are the same , but phase properties are different, i.e. La Union record on Mexico earthquake 1985, Taft record 1952 and random phase are used.

f. Measuring instruments

The axial and shearing forces acting on RBs and the shearing forces on steel dampers are measured by a measuring device comprising load cell installed under every RB and steel damper. The relative horizontal displacements between the shaking table and the superstructure, accelerations and velocities on shaking table and the superstructure are measured. The wave heights of the sloshing model are measured by volumetric type meters.

2. TEST RESULTS

a. Response of isolation device

The maximum responses of horizontal displacements and shear forces of isolators with NRB+SD are shown in Fig.3. The solid lines indicate skeleton curves which are set up in design against each test parameter. The horizontal displacement of the RB whose isolated natural period is made longer by using a high axial stress, don't increases if the initial natural period is set up to 1.0 second. But, the horizontal displacement of the RB whose isolated natural period is made longer increases and enters to a hardening zone if the initial natural period is set up in proportion to the isolated natural period

The maximum responses of horizontal displacements and shear forces of isolation devices with LRB and HRB are shown in Fig.3. The maximum horizontal response strain of isolation device with LRB reaches from 100% to 200% as the same as NRB+SD

The maximum horizontal response strain of isolation device with HRB whose isolated natural period is set up to 2.0 second, is similar to that of NRB+SD. The maximum horizontal displacement of HRB whose isolated natural period is set up to 2.83 seconds reaches from 220% to 260% which is longer than the strain of the other devices. In using an HRB whose isolated natural period is made longer by using a high axial stress, it is necessary to confirm insurance of sufficient damping including material development.

b. Hysteresis loop of isolation device

Hysteresis loops between the shear force and the horizontal displacement of each isolation device are shown in Fig.4. Yield loads of the HRB will be reduced against design values because reducing numbers of isolation devices realizes the HRB with the high axial stress in this study. Hysteresis loops of the other RB satisfy the design value for the most part.

c. Response of superstructure

Distribution of the maximum response acceleration of the superstructure is shown in Table 3. It is found that the maximum response acceleration on each floor of the superstructure is smaller than those of shaking table, so, the effectiveness of isolation system is confirmed. But the maximum response acceleration of the third story with LBR is larger than that of HRB. The higher natural mode of the superstructure is excited because the initial stiffness of LRB is larger than that of HRB.

d. Floor response spectra

The floor response spectra on the second story of the superstructure are shown in Fig.5. It is found that the floor response spectra become smaller as the natural periods of the isolation device are longer according as increase of the axial stress. The peaks of the floor response spectra in a short period domain are exited in the deformation mode of the superstructure for the damping ratio of the superstructure is small because of the steel structure.

e. Response of sloshing

The maximum and minimum wave height responses of the sloshing model which is installed on the second story of the superstructure are shown in Fig.6. The minimum wave height responses of each test case satisfy the allowable limit.

3. CONCLUSION

To investigate applicability of the RB with the high axial stress, shaking table tests for NRB+SD, LRB and HRB are performed.

The results of shaking table tests are summarized as follows.

- In case of NRB+SD and LRB, though an isolated natural period becomes long with a high axial stress, it is confirmed that integrity for seismic isolation devices is ensured.
- In case of HRB whose isolated natural periods are made long by using high axial stress, it is necessary to confirm insurance of sufficient damping in order to reduce the horizontal relative displacement.
- As the natural period of the isolation device is longer according as increase of the axial stress, the horizontal displacement response of the RB becomes larger but the maximum response acceleration and the floor response spectra becomes smaller.

Study on the rupture property of the isolation devices will be performed till next time.

Acknowledgements

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Reference

1) Kato, M. et al. "Design study of the seismic-isolated reactor building of demonstration FBR plant in Japan," Trans. of the 13th SMiRT, Vol.3, Div.K, pp579-584, Brazil, August, 1995

Table 1 Test cases and Parameters

No.	Laminated Rubber Bearing	Isolated Natural Period[1] T_2 (sec)	Ratio of Yield Force to Supporting Load	Initial Natural Period[1] T_1 (sec)			Number of Isolators	Total Weight (tonf)	Axial Stress (kgf/cm²)
				1.0	1.41	2.0			
1	NRB + SD	2.0	0.1	NRB1020[2]	–	–	8	17.2	25
2		2.83	0.1	NRB1028	NRB1428	–	4	17.2	50
3		4.0	0.1	NRB1040	–	NRB2040	4	34.4	100
4	LRB	2.0	0.1	LRB1020	–	–	4	17.2	25
5		2.83	0.1	LRB1028	–	–	4	17.2	50
6	HRB	2.0	0.1	HRB1020	–	–	4	17.2	25
7		2.83	0.1	HRB1028	–	–	4	17.2	50

1) Natural period represents those of prototype.
2) A symbol represents an abbreviation of test case.

Table 2 Similarity Law

Scale of	Similitude
Length	$1/\lambda = 1/15.3$
Velocity	$1/\sqrt{\lambda} = 1/3.91$
Acceleration	1
Time	$1/\sqrt{\lambda} = 1/3.91$
Mass	$1/\lambda^2 = 1/234$
Stress	1

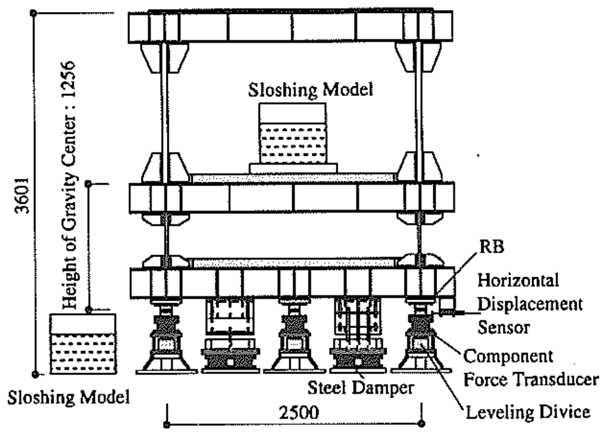
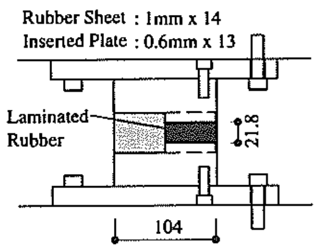
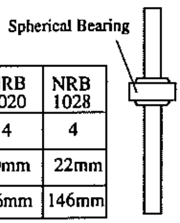


Figure 1. Shaking Table Test Model

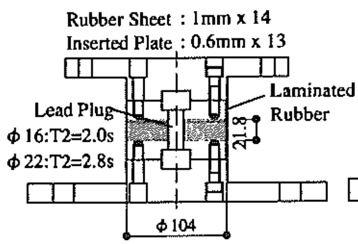


(a) Natural Rubber Bearing

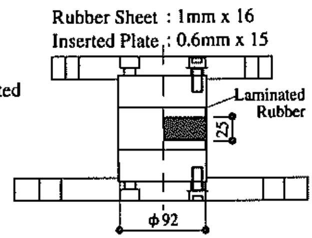
	NRB 1020	NRB 1028
Number	4	4
Diameter	20mm	22mm
Length	136mm	146mm



(b) Steel Damper



(c) Lead Rubber Bearing

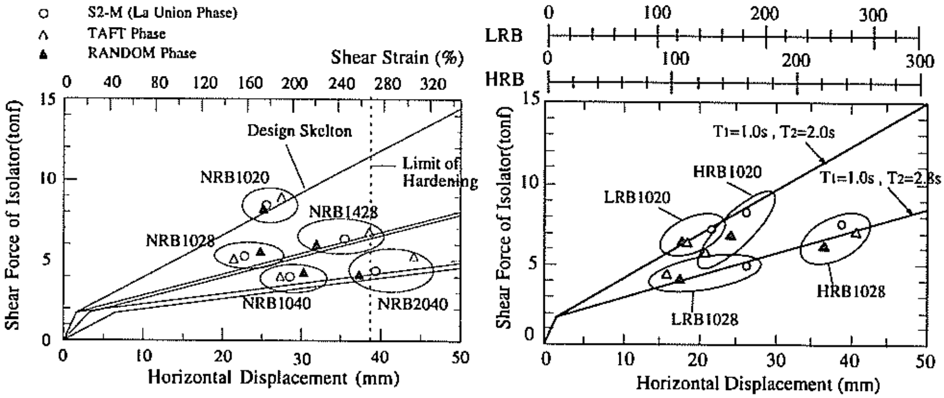


(d) High Damping Rubber Bearing

Figure 2 Laminated Rubeer Bearing for Specimen

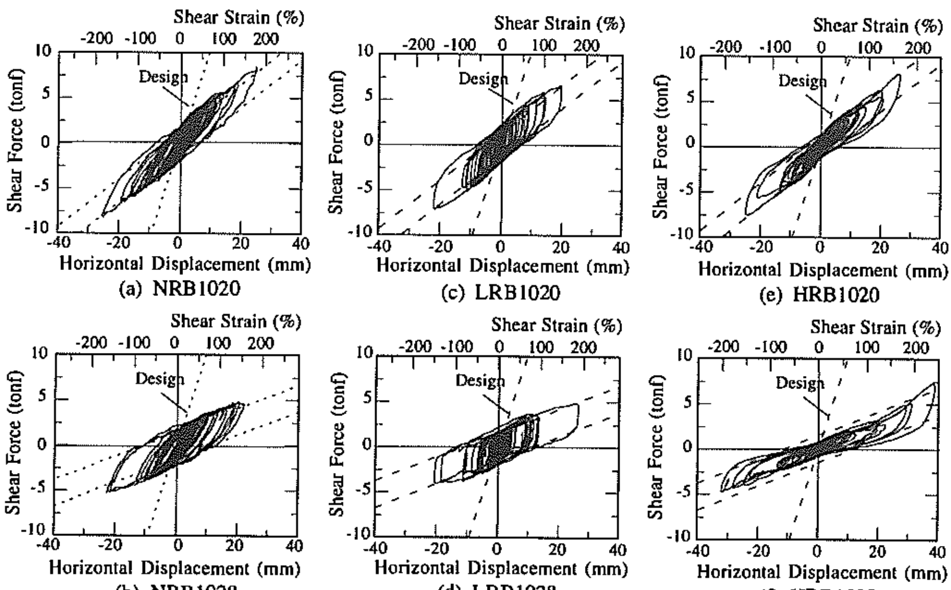
Table 3 Distribution of Maximum Response Acceleration (Unit : Gal)

Position \ Test Case	NRB + SD					LRB		HRB	
	NRB 1020	NRB 1028	NRB 1428	NRB 1040	NRB 2040	LRB 1020	LRB 1028	HRB 1020	HRB 1028
3rd Story	671	558	477	410	350	731	679	533	539
2nd Story	504	359	385	261	274	557	389	514	437
1st Story	577	416	403	288	313	583	427	442	383
Shaking Table	973	954	1006	932	993	837	877	832	866



(a) NRB + SD (a) LRB , HRB

Figure 3 Comparison of Maximum Response Displacement



(a) NRB1020 (c) LRB1020 (e) HRB1020

(b) NRB1028 (d) LRB1028 (f) HRB1028

Figure 4 Relation of Horizontal Displacement - Shear Force

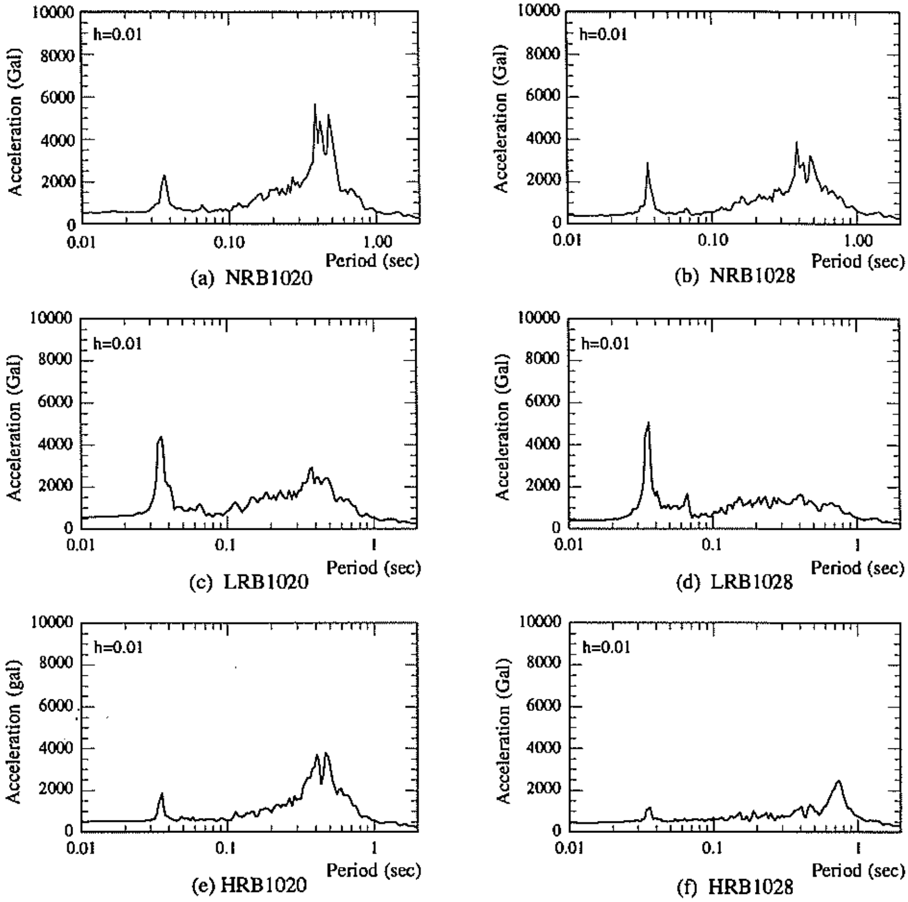


Figure 5 Floor Response Spectra on the 2nd Floor

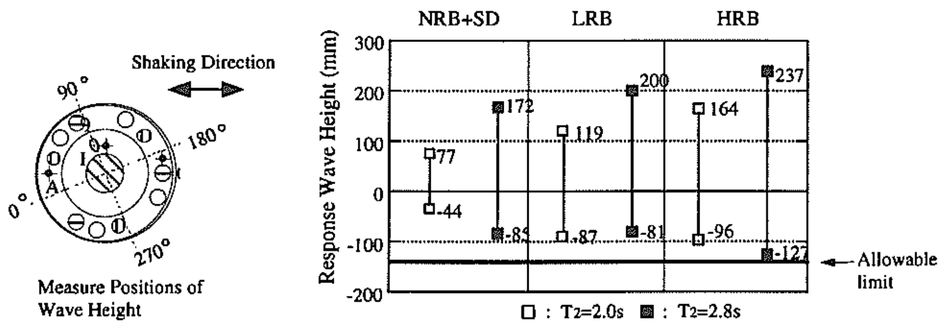


Figure 6 Comparison of the Maximum and Minimum Wave Height in Sloshing (Measure Position A)