IASMiRT

SMiRT 26
50 Anniversary Berlin/Potsdam

Transactions, **SMiRT-26**
Berlin/Potsdam, Germany, July 10-15, 2022
Division V

DYNAMIC CHARACTERISTICS TESTS OF FULL-SCALE LEAD RUBBER BEARING (LRB)

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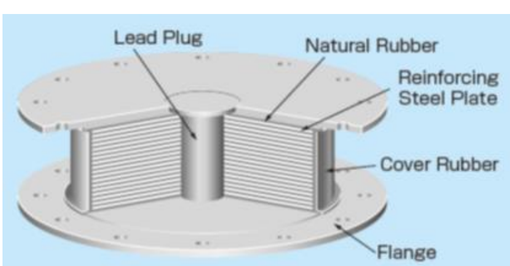
ABSTRACT

Several types of dynamic tests were performed using a full-scale lead rubber bearing (LRB) that has a lead plug embedded at the centre of laminated natural rubber. The horizontal and vertical characteristics of the LRB due to various shear strains, frequencies, cyclic effect and compressive stresses were obtained by the experiments. It was confirmed that the variations of the obtained horizontal and vertical characteristics satisfied allowable variations defined in European standard for Anti-seismic devices (EN15129-2009, See References 1).

INTRODUCTION

In order to improve safety of nuclear power plants (NPPs) against high seismic condition, it had been studied to apply seismic isolation devices to reactor building in NPPs in a past project. A large size of lead rubber bearing (LRB) that has a lead plug embedded at the centre of laminated natural rubber had been developed by Bridgestone Corporation (Figure 1). In addition, static and quasi-static tests using full-scale of the LRB had been conducted to confirm its failure capacity in the project (See Reference 2). Dynamic tests using small size LRBs for typical industries had been conducted to confirm dynamic characteristics, but there was no data of dynamic characteristics of the LRB. In this experiments, dynamic tests were performed to confirm dynamic characteristics of the LRB. Taking into consideration the size and weight of the LRB, dynamic tests were performed using Seismic Response Modification Device (SRMD) at University of California San Diego.



Diameter of isolator D_f	1600	mm
Total thickness of rubber h_R	260	mm
Thickness of rubber sheet t_R	10.0	mm
Number of rubber layers n_R	26	-
Thickness of inner steel plate t_s	6.8	mm
Number of steel plate layers n_s	25	-
Diameter of lead plug D_p	392	mm

Figure 1. Specifications of Full-Scale LRB

OUTLINES OF TESTS

Several types of dynamic tests are performed using full-scale LRBs in this study. Table 2 shows a test series of the dynamic tests. Dependence of horizontal and vertical characteristics due to various shear strains, frequencies, cyclic effect and compressive stresses (ID 2 through 5) were confirmed in accordance with European standard for Anti-seismic devices (EN15129-2009) followed by basic characteristics tests (ID 1). As basic characteristics of the LRB, a horizontal stiffness (post yield stiffness) K_2, a yield strength Q_d and a vertical compressive stiffness K_v are confirmed in this test series. Total three (3) specimens are used for the tests.

Table 2: A Series of Full-Scale Tests

ID	Test Objectives
1	Basic characteristics (K_2, Q_d and K_v)
2	Dependence of horizontal characteristics on rubber shear strain
3	Dependence of horizontal characteristics on frequency
4	Dependence of horizontal characteristics on repeated cycling
5	Dependence of vertical stiffness on compressive stresses

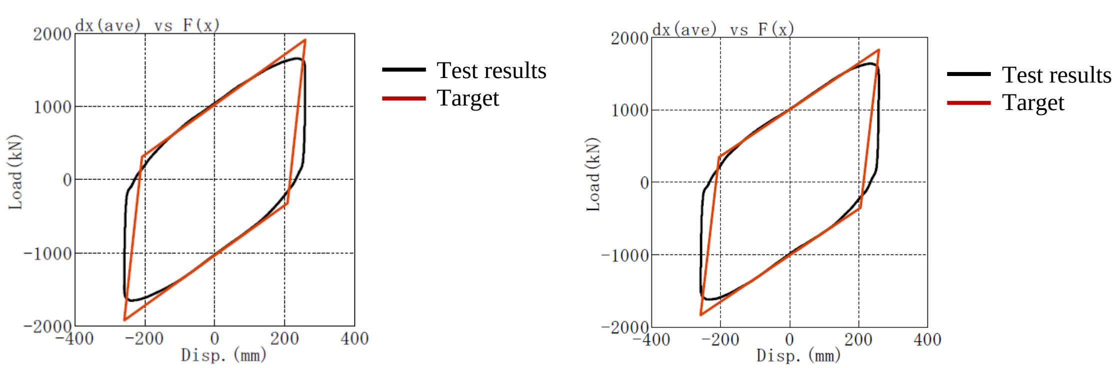
TEST RESULTS

Basic characteristics test (ID1)

The purpose of this test is to confirm the basic characteristics (K_2, Q_d and K_v) of the LRB. The test condition is as follows.

- Shear strain of LRB: ±100% (horizontal displacement is 260mm)
- Compressive stress: 5 MPa const.
- Shaking frequency: Horizontal 0.33Hz (sinusoidal wave)
- Number of test specimen: 2 specimens

Figure 2 shows horizontal load-displacement curve in 3rd cycle. Test results match well to the target of basic characteristics of the LRB. It is also confirmed that there are little differences between the specimens.



<Specimen No.2> <Specimen No.3>

Figrue 2 Horizontal Load-Displacement Curve in 3rd cycle

Table 3 shows the basic characteristics test results. The test results (K_2, Q_d and K_v) are averaged by the results of two (2) specimens. The allowable variations to the basic specifications are specifically set for NPPs considering the seismic design. It is confirmed that the basic characteristics obtained by the test satisfy the allowable variations, except yield strength Q_d. It is considered that the variation of Q_d of the

LRB is caused by an increasing of a diameter of lead plug comparing to LRBs for typical buildings. It is confirmed that a dependence of Q_d on frequency based upon the test data should be incorporated into a basic specification of the LRB which is calculated in delivery inspection (static test). In the following dynamic tests (ID 2 through 5), the basic specification of K_2 and Q_d are set based upon the test results. The basic specification of K_v is set as same as original spec., since K_v is NOT sensitive depend on frequency and it is based upon a lot of delivery inspection data in the past tests (See References 2).

Table 3 Basic Characteristics Test Results

Characteristics	Test Results (Average)	Original Spec.	Ratio	Allowable Variations
K_2 (kN/mm)	<u>3.34</u>	3.17	1.04	0.9~1.1 (±10%)
Q_d (kN)	<u>1058</u>	890	1.19	0.9~1.1 (±10%)
K_v (kN/mm)	6122	<u>7480</u>	0.82	0.8~1.2 (±20%)

Dependence of horizontal characteristics on rubber shear strain (ID2)

The purpose of this test is to confirm the dependence of horizontal characteristics (K_2 and Q_d) on rubber shear strain of the LRB. The test condition is as follows.

- Shear strain of LRB: ±50%, ±75%, ±100%, ±150%, ±200%, ±250%
- Compressive stress: 5 MPa const.
- Shaking frequency: Horizontal 0.33Hz (sinusoidal wave)
- Number of test specimen: 2 specimens

Table 4 shows the minimum and maximum variations of K_2 and Q_d. The variations is calculated by "Test result at 3rd cycle in ID2/basic spec. in ID1" and the allowable variations is set as ±20% in accordance with EN15129. Both K_2 and Q_d satisfy the allowable variation in case that the shear strain is greater than ±75%. It is confirmed that K_2 decreases slightly with the increasing shear strain and Q_d is constant with shear strains.

Table 4 Variations of horizontal characteristics (K_2 and Q_d)

Contents	Test results		Allowable variation
	Min.	Max.	
K_2	-20%	+17%	±20%
Q_d	-8%	+2%	±20%

Dependence of horizontal characteristics on frequency (ID3)

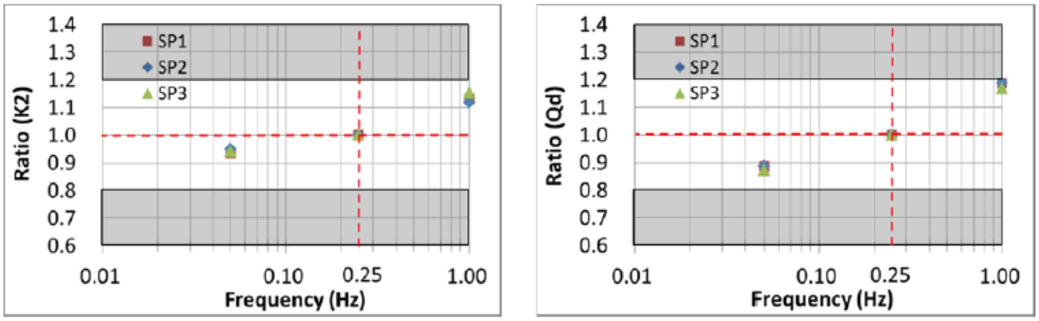
The purpose of this test is to confirm the dependence of horizontal characteristics (K_2 and Q_d) on frequency of shaking. The test condition is as follows.

- Shear strain of LRB: ±100%
- Compressive stress: 5 MPa const.
- Shaking frequency: Horizontal 0.05Hz, 0.25Hz, 1.0Hz (sinusoidal wave)
- Number of test specimen: 3 specimens

Table 5 shows the minimum and maximum variations of the K_2 and Q_d. Figure 3 shows the ratio of K_2 and Q_d on various shaking frequencies. Both K_2 and Q_d satisfy the allowable variation in accordance with EN 15129. According to the test results, it is confirmed that the dependence of horizontal characteristics (K_2 and Q_d) on frequency is greater than past experimental tests for LRBs for typical buildings whose size is smaller than the LRB (test specimens).

Table 5 Variations of horizontal characteristics (K_2 and Q_d)

Contents	Test results		Allowable variation
	Min.	Max.	
K_2	-7%	+15%	±20%
Q_d	-13%	+19%	±20%



<Ratio of horizontal stiffness K_2> < Ratio of yield strength Q_d >

Figure 3 Horizontal characteristics on various shaking frequencies

Dependence of horizontal characteristics on repeated cycling (ID4)

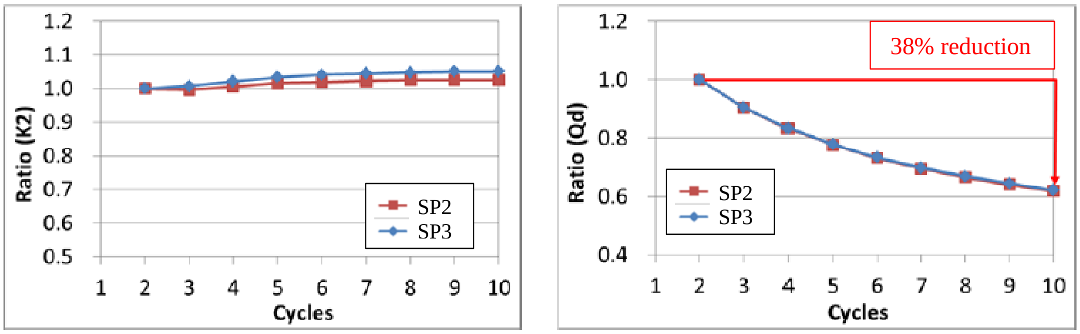
The purpose of this test is to confirm the dependence of horizontal characteristics (K_2 and Q_d) on repeated cycling. The test condition is as follows.

- Shear strain of LRB: ±100%
- Compressive stress: 5 MPa const.
- Shaking frequency: Horizontal 0.1Hz (sinusoidal wave)
- Number of cycle: 10 cycles
- Number of test specimen: 2 specimens

Table 6 shows the variations of the horizontal characteristics (K_2 and Q_d) at 10th cycle comparing to the one at 2nd cycle and 1st cycle. Figure 4 shows the ratio of K_2 and Q_d on repeated cycling. K_2 satisfy the allowable variations in accordance with EN 15129. It is confirmed that the dependence of Q_d on repeated cycling is greater than past experiences of LRBs for typical buildings whose size is smaller than the LRB. It is necessary to conduct a confirmatory analysis to confirm the LRB's behaviour using the test results in next phase study. It would also be necessary to accumulate an additional data of the full-scale LRBs on repeated cycling.

Table 6 Variations of horizontal characteristics (K_2 and Q_d)

Contents	Test results	Allowable variation
K_2 (Ratio of 10th cycle/ 1st cycle)	-8%	±40%
K_2 (Ratio of 10th cycle/ 2nd cycle)	+2%	±30%
Q_d (Ratio of 10th cycle/ 2nd cycle)	-38%	±30%



<Ratio of horizontal stiffness K_2> < Ratio of yield strength Q_d >

Figure 4 Horizontal characteristics on repeated cycling

Dependence of vertical stiffness on compressive stresses (ID5)

The purpose of this test is to confirm the dependence of vertical stiffness (K_v) on compressive stresses. The test condition is as follows.

- Shear strain of LRB:0% (const.)
- Compressive stress: 5 MPa ± 2.5MPa
- Shaking frequency: Vertical 0.0125Hz, 0.33Hz (sinusoidal wave)
- Number of test specimen: 2 specimens

Figure 5 shows the variations of the vertical stiffness (K_v) on compressive stresses. The ratio of K_v is calculated by "test results at 3rd cycle in ID 5/basic spec. in ID1". The maximum variation of K_v is -18% comparing to the basic specification of the LRB. It is confirmed that the variation obtained by the test is within the allowable variations in accordance with EN 15129 (±30%).

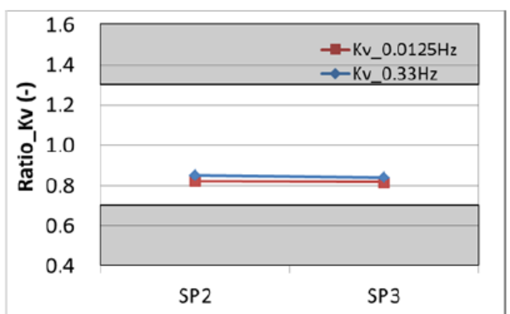


Figure 5 Vertical stiffness on compressive stresses

Summary of Test Series (ID 2 through 5)

Table 7 shows the summary of the results. The horizontal and vertical characteristics of the LRB obtained by the experiments satisfy the allowable variations in accordance with EN 15129. It is confirmed that further investigations are necessary regarding a reduction of Q_d of the LRB on repeated cycling to confirm an impact on seismic design of base isolated reactor building in an NPP.

Table 7 Summary of the Results (ID 2 through 5)

ID	Test Objectives	Allowable Variations	Test Results
2	Dependence of horizontal characteristics on rubber shear strain	K_2 : ±20% Q_d : ±20%	K_2 :-20%~+17% Q_d :-8%~+2%
3	Dependence of horizontal characteristics on frequency	K_2 : ±20% Q_d : ±20%	K_2 :-7%~+15% Q_d :-13%~+19%
4	Dependence of horizontal characteristics on repeated cycling	K_2 : ±30% (2nd/10th cycle) ±40% (1st/10th cycle) Q_d : ±30% (2nd/10th cycle)	K_2 :+2%(2nd/10th) -8%(1st/10th) Q_d : -38% (2nd/10th)
5	Dependence of vertical stiffness on compressive stresses	K_V : ±30%	K_V : -18%

CONCLUSIONS

Several types of dynamic tests were performed using full-scale lead rubber bearings (LRBs) that have a lead plug embedded at the centre of laminated natural rubber. The horizontal and vertical characteristics of the LRB due to various shear strains, frequencies, cyclic effect and compressive stresses were obtained by the experiments. It was confirmed that the variations of the obtained horizontal and vertical characteristics satisfied allowable variations defined in European standard for Anti-seismic devices (EN15129-2009).

REFERENCES

European Committee for Standardization (CEN) (2009), Anti-seismic device, EN15129.

T. Imaoka et al (2015), *DEVELOPMENT OF EVALUATION METHOD FOR SEISMIC ISOLATION SYSTEMS OF NUCLEAR POWER FACILITIES -BREAK TEST OF FULL SCALE LEAD RUBBER BEARINGS FOR NUCLEAR FACILITIES, PART 1 OUTLINE OF BREAK TEST OF LRB OF 1.6M IN DIAMETER-*, SMiRT23, Manchester, United Kingdom