Design of Small Size Laminated Rubber Bearings Applicable for Seismic Isolation of Individual Nuclear Components

Gyeong-Hoi KOO[a*], Tae-Myung SHIN[b]
[a] *Korea Atomic Energy Research Institute, Daedeok-daero 989-111, Yuseong-gu, Daejeon, 305-335, Korea*
[b] *Korea University of Transportation, Daehakro 50, Chungju, 27469, Korea*
**Corresponding author: ghkoo@kaeri.re.kr*

1. Introduction

Recently, there are many efforts globally to enhance the seismic capacity of nuclear power plants. As one of challengeable technical ways to achieve this goal, the seismic isolation design with the laminated rubber bearing(LRB) has been officially considered as a promising candidate in Korea. These efforts in Korea are basically on the concept of whole seismic isolation for nuclear island including reactor building with large size LRBs. To confirm and give a credit for large size LRB application for nuclear island, it is necessary to be incubated with further technologies and test data [1~7].

In this paper, the design of the small size LRBs are designed and the specifications are proposed to be used for a seismic isolation of individual nuclear components. Actually, it is known that the design of small size LRB is more difficult to design, fabricate and substantiate its performance. Four types of LRB size are designed in this paper with target capacities of vertical weight as 1 ton, 2 tons, 5tons and 10tons.

2. Design Conditions

The required design conditions for small size LRB design are as follows;

- Long-term vertical design load
- Short-term vertical design load
- Horizontal isolation frequency
- Vertical design natural frequency
- Design shear strain and deflection for SSE(Safe Shutdown Earthquake)
- Target shape factors (S_1 and S_2)

In selection of rubber material, the linear range of behavior, rupture limits, long-term aging, creep, etc. should be considered.

3. Horizontal Stiffness Design

In design of horizontal stiffness of LRB, the vertical load effects should be considered because of P-delta effects. When considering the design vertical load, the horizontal stiffness is expressed as follows;

$$K_H = \frac{1}{K_1 + K_2 \cdot K_3}$$

where

$$K_1 = \frac{H_B}{S_S}$$

$$K_2 = \frac{H_B^3}{12 \cdot S_b}, \qquad K_3 = \left(1 + \frac{P}{S_S}\right)^2$$

In above equation, P and H_B represent a vertical load applying to upper flange of LRB and total height of LRB including rubber and steel respectively. The symbols of S_b, and S_s represent a bending stiffness and a shear stiffness respectively and expressed as follows;

$$S_b = \overline{E}_b I [n t_R + (n-1) t_S] / n t_R$$

$$S_s = G A_s [n t_R + (n-1) t_S) / n t_R ,$$

where n, t_R, and t_S represent a number of rubber layer, a rubber layer thickness and a steel thickness respectively. $\overline{E}_b$ is the apparent compressive modulus of rubber considering the bulk compression for bending of rubber layer. This is calculated by using the bulk compressive modulus of E_∞ as follows;

$$\overline{E}_b = E_b E_\infty / (E_b + E_\infty)$$

In above equation, E_b is the apparent compressive modulus without compressive characteristics of rubber and can be calculated as follows;

$$E_b = E_o\left(1 + \frac{2}{3}\kappa S_1^2\right) \approx 3G\left(1 + \frac{2}{3}\kappa S_1^2\right)$$

In above equation, k and E_o represent the hardness modification factor and elastic modulus of rubber respectively. S_1 indicates the first shape factor of LRB. S_1 is defined as $(D_o - D_i)/(4t_R)$ for circular rubber layer.

The target seismic isolation frequencies corresponding to 1 ton design load is 1.0Hz, and 0.7Hz commonly for 2 ton, 5 ton, and 10 ton loads. The designed horizontal stiffness for the design loads are 31.4kN/m, 34kN/m, 76.5kN/m, and 173.6kN/m respectively.

4. Vertical Stiffness Design

The target LRB vertical frequencies corresponding to the design loads are 15Hz for both 1 ton and 2 ton loads and 17Hz for both 5 ton and 10 ton loads.

The design equation for vertical stiffness is as follows;

$$K_V = \frac{A_S \cdot \overline{E_c}}{n \cdot t_R}, \qquad \overline{E_c} = \frac{E_\infty \cdot E_c}{E_\infty + E_c}$$

5. Tentative Design Specifications

The tentative design parameters of small size LRB for four types are presented in Table 1.

Table 1. Design spec. for small size LRB

	1 ton	2 tons	5 tons	10 tons
RUBBER MATERIAL				
SHEAR MODULUS (MPa)	0.3	0.3	0.3	0.5
YOUNGS MODULUS (MPa)	0.9	0.9	0.9	1.5
BULK MODULUS (GPa)	1.96	1.96	1.96	1.96
HARDNESS MOD FACTOR	0.85	0.85	0.85	0.85
LRB SIZE				
OUTER DIAMETER (mm)	65	74	120	158
INNER DIAMETER (mm)	0	0	20	20
RUBBER THICKNESS (mm)	2.4	2.2	2.3	3.0
NUMBER OF RUBBER LAYER	10	12	16	17
TOTAL RUBBER HEIGHT (mm)	24	26.4	36.8	51
STEEL THICKNESS (mm)	1.6	1.6	2	2.3
TOTAL LRB HEIGHT (mm)	38.4	44	66.8	87.8
LRB PERFORMANCE				
VERTICAL LOAD (Tons)	1	2	5	10
HORIZONTAL STIFFNESS (kN/m)	31.43	33.95	76.53	173.6
VERTICAL STIFFNESS (MN/m)	9.309	16.835	49.68	109.25
HORIZONTAL FREQUENCY (Hz)	0.9	0.67	0.62	0.66
VERTICAL FREQUENCY (Hz)	15.4	14.61	15.87	16.64
SHEAR STRAIN RATIO (%)	200	200	200	200
DESIGN HORIZONTAL DISP. (mm)	50	50	70	100
BUCKLING LIMIT LOAD (kN)	17.8	30.2	117.5	339.0
BUCKLING LIMIT MARGIN	1.82	1.54	2.4	3.46
SHAPE FACTORS				
S1	6.7	8.4	10.9	11.5
S2	2.7	2.8	3.3	3.1

6. Evaluation of LRB Instability

The LRB instabilities can be evaluated by Euler's method without shear deflection as follows;

$$P_E = \frac{\pi^2 \cdot S_b}{T_B},$$

where,

$$S_b = \frac{\overline{E_b} \cdot I[n \cdot t_R + (n-1)t_S]}{n \cdot t_R}$$

$$T_B = n \cdot t_R + (n-1) \cdot t_S$$

From the Table 1, we can see that the proposed four LRBs have sufficient margin of buckling instability.

7. Conclusions

In this paper, the small size LRB are designed and proposed the design specifications for a purpose of seismic isolation of individual nuclear components. The manufacturability of the small sized LRB is already investigated by the vendor but the performance tests should be performed to validate the design specifications.

It is expected that these small sized LRB can significantly enhance the seismic capacity of nuclear power plants if these technologies are substantiated by tests.

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REFERENCES

[1] G.H. Koo, J.H. Lee and B. Yoo, "Mechanical Characteristics of Laminated Rubber Bearings for Seismic Isolation," Journal of the Earthquake Engineering Society of Korea, Vol. 1, No. 2, pp. 79-89, 1997.

[2] G.H. Koo, J.H. Lee and B. Yoo, "Performance Experiments and Analysis of Nonlinear Behavior for HDRB Using in Seismic Isolation, "Journal of the Earthquake Engineering Society of Korea, Vol. 2, No. 4, pp.73-85, 1998.

[3] G.H. Koo, J.H. Lee, and Y. Bong, "Seismic Response Analyses of Seismically Isolated Structures Using the Laminated Rubber Bearings," Journal of the Korean Nuclear Society, Vol. 30, No. 5, pp.387-395, 1998.

[4] G.H. Koo and Yasuki Ohtori, "Loading Rate Effects of High Damping Seismic Isolation Bearing on Earthquake Responses," KSME International Journal, Vol. 12, No. 1, pp.58-66, 1998.

[5] G.H. Koo, H.Y. Lee, and B. Yoo, "Seismic Design and Analysis of Seismically Isolated KALIMER Reactor Structures," Journal of the Earthquake Engineering Society of Korea, Vol. 3, No. 1, pp.75-92, 1999.

[6] G.H. Koo, J.H. Lee, and B. Yoo, and Yasuki Ohtori, "Evaluation of Laminated Rubber Bearing for Seismic Isolation Using Modified Macro-Model with Parameter Equations of Instantaneous Apparent Shear Modulus," Engineering Structures, Vol. 21, No. 7, pp.594-602, 1999.

[7] G.H. Koo, J.H. Lee, H.Y. Lee, and B. Yoo, "Stability of Laminated Rubber Bearing and its Application to Seismic Isolation," KSME International Journal, Vol. 13, No. 8, pp. 595-604, 1999.