# A Study on the Design Value of Small Laminated Rubber Bearings for Seismic Isolation of Nuclear Power Plant Equipment

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## 1. Introduction

As a major accident such as the Fukushima nuclear power plant(NPP) accident occurred in 2011, NPP are demanding higher safety against earthquakes. In order to protect NPP from earthquakes, seismic isolation are being developed around the world[1]. In Korea, anxiety about NPP has increased due to the following earthquakes in Gyeongju in September 2016 and Pohang in November 2017. Therefore, efforts are being made to secure the seismic safety of existing NPP.

APR1400 is designed to withstand 0.3g of SSE(Safety Shutdown Earthquake), and it is known that the seismic performance meets about 0.5g. APR1400 has various structures and equipments, among these are facilities vulnerable to earthquakes. If the seismic performance target of APR1400 is raised to more than 0.6g, the range of vulnerable seismic equipments may increase somewhat.

This study examines the upward effect of seismic performance of NPP through the application of seismic isolation technology to major equipment of NPP and prove the feasibility of applying seismic isolation technology. Finally, we want to complete the design and manufacture of the optimal seismic isolation device.

Prior to this, it is necessary to examine the design direction of the isolation device. In this study, the research is carried out based on the four design plans (1, 2, 5, 10ton of upper Mass) proposed by Korea Atomic Energy Research Institute(KAERI). In this paper, carries out a preliminary assessment the design and performance of the isolation device. By comparing the values calculated based on the technical standards with the results of the ANSYS analysis.

## 2. Design of Laminated Rubber Bearing

The concept of seismic isolation is based on the characteristics of earthquakes with strong short-period components and weak long-period components. Seismic isolation reduces the magnitude of the seismic force transmitted to the structure by artificially increasing the natural period of the structure. In this study, we will examine the laminated rubber bearing(LRB) among various isolation devices that exhibit such an isolation effect.

### *2.1 Geometry*

In this study, the design values and performance evaluation of the 1ton and 2ton LRBs, which is the simplest form of the four designs proposed in the previous research[2,3], are examined. The shape and specifications of the LRBs are shown in Fig. 1 and Table 1, respectively.

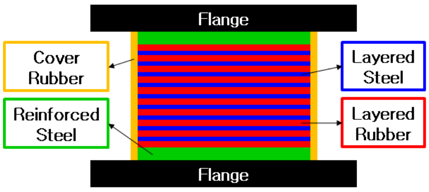

Fig. 1. Cross-sectional shape of LRB and name of each part

Table 1. Design Spec for 1ton(2ton) mass LRB

| | Diameter (mm) | Thickness (mm) | Number of elements |
|---|---|---|---|
| Flange | 165(170) | 15(15) | 2(2) |
| Reinforced Steel | 65(74) | 10(10) | 2(2) |
| Layered Steel | 65(74) | 1.6(1.6) | 9(11) |
| Layered Rubber | 65(74) | 2.4(2.2) | 10(12) |
| Cover Rubber | 58.4(64) (Height) | 5(5) | 1(1) |

### *2.2 Material Properties*

As a material for LRB, steel (SS400) and rubber (Money-Rivlin) are used[3]. The properties values of rubber materials expected to significantly affect the performance of the LRB are shown in Table 2.

Table 2. Rubber Material Properties

| Rubber(Mooney-rivlin) | | |
|---|---|---|
| G | Shear Modulus(MPa) | 0.3 |
| $E_o$ | Young's Modulus(MPa) | 0.9 |
| $E_\infty$ | Bulk Modulus(GPa) | 1.96 |
| k | Hardness Mod. Factor | 0.85 |

### *2.3 Design Value*

In this study, it is assumed that 1 ton (or 2 tons) mass is loaded for each LRB. The horizontal and vertical stiffness of LRB was calculated using the expressions in Table 3 below, referring to ISO 22762, and the preceding study[2,3,4].

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Table 3. LRB Design Equations

| | Explanation | Equation |
|---|---|---|
| $D_o$ | Outer Diameter(mm) | - |
| $D_i$ | Inner Diameter(mm) | - |
| $n$ | Number of Rubber Layer | - |

| | | |
|---|---|---|
| $t_r$ | Rubber Thickness (mm) | - |
| $t_s$ | Steel Thickness (mm) | - |
| $P$ | Vertical Load (N) | - |
| $H_B$ | Total LRB Hieght (mm) | $H_B = [nt_R + (n-1)t_s]$ |
| $S_1$ | Shape Factor | $S_1 = (D_o - D_i)/(4t_R)$ |
| $A_s$ | ShearArea (mm$^2$) | $A_s = \pi(D_o^2 - D_i^2)/4$ |
| $E_b$ | Apparent compressive modulus Without compressive characteristics of rubber (MPa) | $E_b = E_o\left(1 + \frac{2}{3}kS_1^2\right)$ |
| $\overline{E_b}$ | Apparent compressive modulus of rubber considering the bulk compression for bending of rubber (MPa) | $\overline{E_b} = E_b E_\infty/(E_b + E_\infty)$ |
| $S_s$ | Shear Stiffness (N) | $S_s = GA_s H_B/nt_R$ |
| $S_b$ | Bending Stiffness (N·mm$^2$) | $S_b = \overline{E_b} I H_B/nt_R$ |
| $k_1$ | (mm/N) | $\mathrm{k}_1 = H_B/S_s$ |
| $k_2$ | (mm/N) | $k_2 = H_B^3/12S_b$ |
| $k_3$ | - | $k_3 = (1 + P/S_s)^2$ |
| $k_H$ | Horizontal Stiffness (N/mm) | $k_H = 1/k_1 + k_2 \cdot k_3$ |
| $E_c$ | Apparent Young's modulus corrected for bulk compressibility depending on the S$_1$ (MPa) | $E_c = E_o(1 + 2kS_1^2)$ |
| $\overline{E_c}$ | Apparent Young's modulus corrected, if necessary, by allowing for compressibility (MPa) | $\overline{E_c} = \frac{E_c E_\infty}{E_c + E_\infty}$ |
| $k_V$ | Vertical Stiffness (N/mm) | $k_V = \frac{A_s \cdot \overline{E_c}}{n \cdot t_R}$ |

## 3. Modal Analysis

In this study, a finite element model of a LRB is created using ANSYS Mechanical 19.0, a commercial finite element analysis program.

### *3.1 Interpretation Method*

The mode analysis of the LRB is performed using the above model. Preliminary evaluation of the performance of the LRB is performed by checking the target horizontal and vertical natural frequency of the LRB from the analysis results. Table 4 shows information about the ANSYS mode analysis settings.

Table 4. About Analytical Settings

| | |
|---|---|
| *Analysis* | *Modal* |
| *Load* | *1000 kg distribution mass(upper flange)* |
| *Contact* | *Set all interface contact conditions to Bonded* |
| *Mesh* | *Default* |
| *B.C.* | *fixed support(lower flange)* |

### *3.2 Comparison of Results*

Table 5 shows the calculations of the horizontal and vertical natural frequencies compared to the analysis results of ANSYS. In addition, Fig. 2 shows the horizontal and vertical mode shape of the 1ton LRB.

Table 5. Horizontal and Vertical Natural Frequency of LRB

| | | Calculation | Analysis | Error(%) |
|---|---|---|---|---|
| 1ton | Horizontal (Hz) | 0.9 | 1.25 | 38.9 |
| | Vertical (Hz) | 15.4 | 14.83 | 3.7 |
| 2ton | Horizontal (Hz) | 0.67 | 0.9 | 25.6 |
| | Vertical (Hz) | 14.61 | 11.63 | 20.4 |

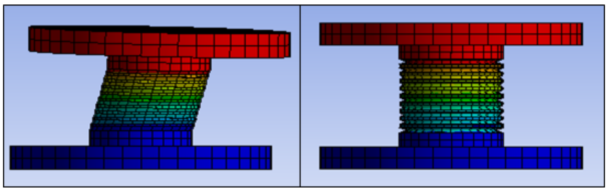

Fig. 2. Horizontal and Vertical Mode Shape of 1ton LRB

Preliminary evaluation of the performance of the LRB is possible from the mode analysis results. It can be seen that the horizontal and vertical natural frequency values of the LRB differ slightly compared to the results Calculated based on Table 3.

## 4. Conclusions

The analysis results above show that there is a error between the calculated values by the design equation and the analysis results of the ANSYS. It is judged that this error is due to the slightly different material value (assuming a simplified elastic modulus) of the rubber entered in the ANSYS analysis compared to the equation for calculating vertical and horizontal stiffness. If material properties obtained from the performance test of rubber materials are applied to the ANSYS analysis, the more accurate evaluation of the performance of the LRB based on the ANSYS analysis results is expected. Also, It is assumed that reliability of the analysis results of ANSYS can be demonstrated through comparative verification with the performance test results of the LRB.

## Acknowledgement

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