Development of a 20-ton 3D Small Seismic Isolator for Microreactors and Small Modular Reactors

Bong Yoo [a*], Tae-Young Ryu [a], Yun-Hwan Maeng [a], Jae-Han Lee [b]
[a]*BEES, #702, Happylaum,674 benji Daipyung-dong, Sejong city, 30152, Republic of Korea*
[b]*KAERI, Advanced Reactor Dept., 111 Daedeok-daero 989 beon-gil, Yuseong-gu, Daejeon, 34057, Republic of Korea*
[*]*Corresponding author: byoo@bees.pro*

***Keywords :** 3D seismic isolator, lead rubber bearing, stacking of disc springs, seismic isolation frequencies, DBE, BDBE, Microreactor, SMR*

1. Introduction

Application of a 3D seismic base isolation (SI) system for nuclear facilities has been explored for various nuclear reactor types, such as KALIMER (Sodium Fast Reactor) [1, 3-5], JSFR[2], STARLM, and Kemmerer. Meanwhile 2D horizontal SI systems have already been used in Koeberg, Cruas, ITER, and JHR. Several studies on application of 3D SI in nuclear structures have shown that maintaining a vertical isolation frequency around 3 Hz can effectively reduce the vertical responses. However reducing the vertical isolation frequency further to 1 Hz can lead to pronounced rocking effects [6,7].

A design method for creating a 20-ton 3D isolator - integrating a Lead–Rubber Bearing (LRB) for horizontal isolation and a disc spring assembly for vertical isolation- has been developed to ensure smooth multidirectional movement under BDBE (0.5g horizontal and 0.33g vertical earthquakes) for microreactors and Small Modular Reactors (SMR). While specifics (like dimensions, layer thicknesses, etc.) depend on project load and code requirements, the outline below demonstrates how to design and combine these two components into a single 20-ton 3D isolation device.

2. Design Methods and Results

2.1 Performance Requirements

Design loads are gravity loads of 20 tons per 3D isolator for the relevant structures/systems/components. The horizontal and vertical seismic demands are specified up to 0.5 g, and up to 0.33 g, respectively. Target isolation frequencies are horizontally in the range 0.5–1.0 Hz for effective base isolation, and vertically higher than horizontal but still “low” relative to a fixed structure—say 1.0–2.0 Hz.

Damping requirements of 3D isolators to be more than 12% but limited to 24% in horizontal directions [8], and 10% or more in vertical directions. Horizontal damping provided by the yielding lead plug in the LRB (plus rubber hysteresis), vertical damping may be relatively small in disc springs (Belleville springs), so additional friction devices (or alternative damping measures) may be considered if higher damping is needed.

The design shear strain of 3D isolators to be within 100% at design vertical load at DBE (0.3g / 0.2g in horizontal and vertical directions), and maximum shear strain of 300% at BDBE in horizontal directions.

The displacement capacity of 3D isolator must accommodate the lateral displacement demanded by 0.5 g shaking (plus code specified margins). The disc spring stack must allow enough vertical travel to achieve the desired vertical isolation frequency and also accommodate vertical peak acceleration (0.33g) without bottoming out. And the 3D isolator should allow free up-and-down movement of 10~15 cm to limit the rotational effects.

2.2 Design Horizontal Isolation Subsystem (LRB)

Based on 0.5 Hz isolation frequency, the overall diameter of the isolator is determined to be 450 mm, with lead plug diameter of 80 mm, and total rubber thickness 320 mm (32 layers of 10 mm each) [9].

These dimensions help ensure adequate shear strain capacity and energy dissipation.

2.3 Design Vertical Isolation: 400 mm Disc–Spring Stack

Because typical rubber bearings have high compression stiffness, disc springs are used in combination with a guide tube on top of the LRB to reduce overall vertical stiffness to ~1–2 Hz.

- Series Connection:

The disc-spring assembly sits above (or below) the LRB, so that entire vertical load passes through the disc springs first. In a series arrangement, the overall vertical stiffness is basically the stiffness of the disc spring stack itself.

- 400 mm Diameter Disc Springs

Typically, a 400 mm OD disc might carry ~100 kN at ~2 mm deflection. Hence, stiffness of one disc:

k_1 = 100,000 N / 0.002 m = 5×10^7 N/m

- Target Vertical Frequency & Stiffness

Depending on the desired frequency (say 1.5–2.0 Hz), the table below gives approximate target stiffness:

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Table I: Target Vertical Frequency & Stiffness

f_v	$\omega = 2\pi f_v$	$K_v = m\,\omega^2$	Static Defl. δ = 200 kN / K_v
1.5 Hz	9.42 rad/s	~1.77×10^6 N/m	~113 mm
1.75 Hz	10.9 rad/s	~2.42×10^6 N/m	~83 mm
2.0 Hz	12.5 rad/s	~3.16×10^6 N/m	~63 mm

- Determining Series and Parallel Arrangement

Required static deflection is e.g., for 2.0 Hz, ~63 mm deflection under 200 kN and each disc: ~2 mm at 100 kN. So to get ~63 mm total stroke, 32 discs in series (32 × 2 mm ≈ 64 mm). The capacity of one disc is 100 kN, and the total device must hold 200 kN. So parallel columns, n_p =2.

The total vertical stack stiffness is checked that single disc stiffness is $k_1 = 5 \times 10^7$ N/m, then one column of 32 discs in series; $k_{series} = k_1 / 32 = 5 \times 10^7 / 32 \approx 15.63 \times 10^5$ N/m. With 2 columns in parallel, the total stiffness is $2 \times 15.63 \times 10^5$ N/m = 3.13×10^6 N/m which is close to 3.16×10^6 N/m for 2.0 Hz.

2.4 Integration for 3D Motion

The final 3D isolator as shown in Figure 1 includes a LRB for horizontal isolation of 0.5 Hz, a disc spring stack for vertical isolation of 2.0 Hz, and a guide tube or equivalent mechanism to prevent lateral buckling of the disc springs and ensure smooth multidirectional movement.

It accommodates combined seismic loads of 0.5g horizontally and 0.33g vertically for a 20-ton payload. The disc springs provide the necessary vertical flexibility and can move up to ±10–15 cm without bottoming out. The LRB handles large horizontal displacements at up to 300% shear strain. Sliding or low-friction surfaces may be employed to avoid jamming when the top plate tilts under seismic shear.

3. Conclusions

This paper proposes a design for a 20-ton 3D seismic isolator intended for seismic base isolation for microreactors and SMRs. It combines a 450 mm diameter lead LRB (with 80 mm lead plug) for 0.5 Hz horizontal isolation and a 400 mm disc-spring stack for 2.0 Hz vertical isolation. The 3D isolator is designed to protect against up to 0.5 g horizontal and 0.33 g vertical seismic inputs, enabling multidirectional movement.

The proposed design method for the 3D seismic isolators can be used for different heavier or lighter vertical loads required in microreactors, SMRs and NPPs.

Further studies on manufacturing and testing the prototype 3D isolator are necessary to confirm; smooth, decoupled horizontal shear in the rubber bearing, controlled, softer vertical compression in the disc springs, sufficient stroke for ±0.33g vertical fluctuations, and adequate damping from the lead plug in horizontal motion. Additionally, seismic response analyses for base isolated microreactors and SMRs can quantify the seismic margins and the economic benefits of employing 3D seismic base isolation system to microreactors and SMRs.

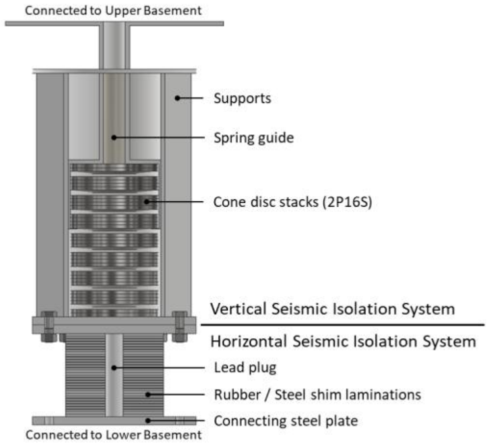

Fig. 1 Schematics of Integral 3D-LRB

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