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Seismic Response of a Microreactor under Fixed-Base, 2D, and 3D Base Isolation

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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, Kairos [6], and Kemmerer [7]. Microreactors intended for deployment in regions of moderate seismicity must be resilient against both horizontal and vertical earthquake components. Conventional fixed-base support systems can subject the compact module to unacceptable accelerations, while 2D base isolation systems are effective against horizontal demands but cannot sufficiently reduce vertical accelerations.

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 for microreactors and Small Modular Reactors (SMR) [8].

This study compares seismic responses of a 120-ton microreactor module under fixed-base, 2D isolation, and 3D isolation subjected to artificial ground motions scaled to 0.3g.

2. Methods and Results

2.1 Ground Motions

Artificial time histories were generated using P-CARES [9], and spectrally matched to a target design spectrum representative of moderate seismicity sites. Each motion was scaled to PGA = 0.3g for horizontal and vertical components. Note that vertical components are commonly with a V/H ratio of 2/3, scaled to 0.2g. Figure 1 shows a horizontal acceleration time history generated from GMRS of PGA 0.3g (1g=386.09 in/sec2).

2.2 3D 20-ton isolator

Design loads are gravity loads of 20 tons per 3D isolator and the 3D isolator as shown in Figure 2 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 to prevent lateral buckling of the disc springs and ensure smooth multidirectional movement.

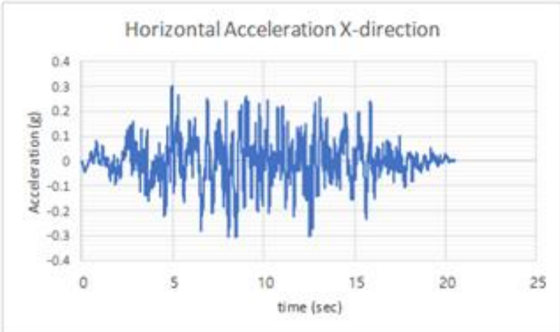


Fig. 1 Horizontal Artificial Acceleration Time History (PGA=0.3g=116.6 in/s2)

The design shear strain of 3D isolators to be within 100% at design vertical load at DBE (0.3g in horizontal and vertical directions), and maximum shear strain of 300% at BDBE 0.5g in horizontal directions.

Damping of the 3D isolator is determined 15% for horizontal direction and 10% for vertical direction, respectively, to meet the requirements to be more than 12% but limited to 24% in horizontal directions [10], and 10% or more in vertical directions.

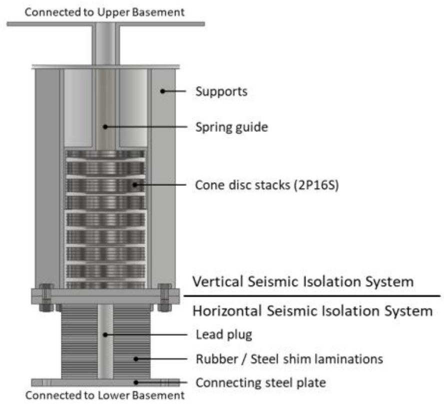


Fig. 2 Schematics of Integral 3D-LRB

The displacement capacity of 3D isolator [11] should accommodate the lateral displacement demanded by 0.5 g shaking (plus code specified margins). The disc spring stack should 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.

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).

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

To meet target vertical isolation frequency of 2.0 Hz and to get ~63 mm total static stroke (32 × 2 mm ≈ 64 mm), 32 discs of 400 mm diameter Disc Springs in series with 2 columns in parallel are determined. Typically, a 400 mm OD disc might carry ~100 kN at ~2 mm deflection.

2.3 Modeling & Numerical Methods

The microreactor is modeled as a rigid-body with six degrees of freedom. The 3D-20 ton Isolators are modelled by simplified linear stiffness and damping coefficients as below for 3d isolation system using total number of 6 isolators for 120 ton microreactor.

Kh, Kv = m ω2, (1)

Ch, Cv = 2 ζ m ω (2)

Where ω = 2πf, fh = 0.5Hz, fv = 2.0Hz, ζ = 0.15 for horizontal, and ζ=0.07 for vertical isolation system.

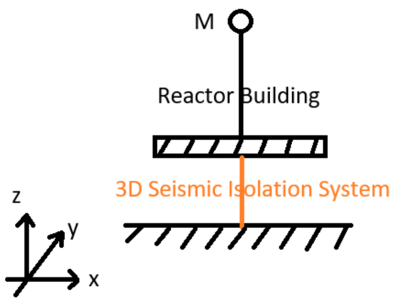


Fig.3 Simplified 3D seismic isolation system model

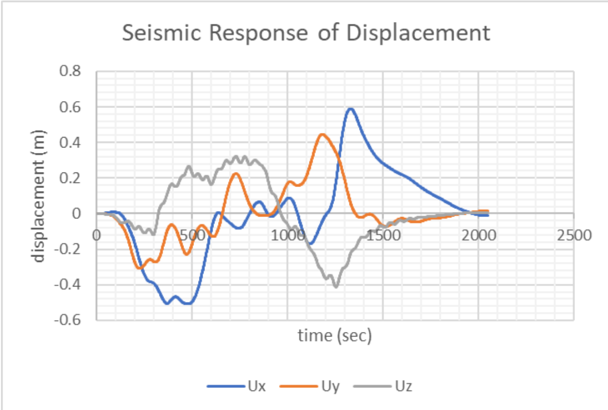
Linear time-history analyses were carried out using the ANSYS [12].

2.4 Results & Discussion

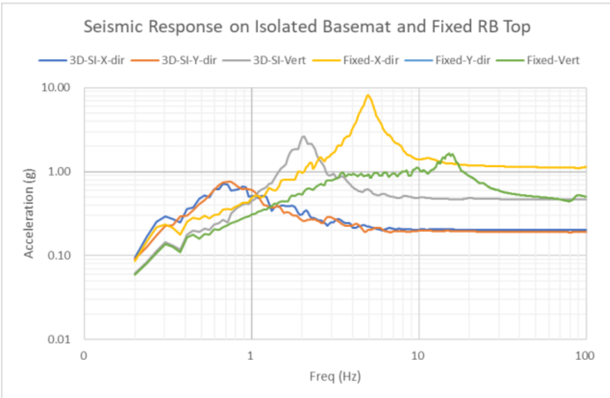
Comparisons were made between fixed-base, 2D isolated, and 3D isolated systems. Seismic responses include isolator displacements, and horizontal and vertical acceleration responses as typically shown in Figure 4. Preliminary results show substantial reductions in horizontal acceleration (7.8g to 0.2g of max. acceleration, 1.1g to 0.2g of ZPA over 3Hz) and vertical acceleration (1.6g to 0.5g of max. acceleration, 1.0g to 0.5g in frequency range of 4~30Hz) in the 3D system compared to the fixed-base and 2D systems.

3. Conclusions

This study highlights the advantages of 3D seismic isolation for microreactors, providing significant reductions in both horizontal and vertical seismic demands. While 2D isolation remains effective for reducing horizontal forces, it does not adequately control vertical acceleration peaks.



a) Displacement History



b) FRS at Upper Foundation Mat

Fig. 4. Seismic Displacement/Acceleration Responses (3D SI System/Fixed base)

Future work will include manufacturing and testing the prototype 3D isolator, moat design and analysis, displacement demand for 3D isolation system, probabilistic fragility analysis and soil-structure interaction modeling, and the economic benefits of employing 3D seismic base isolation system to microreactors and SMRs.

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