# Acceleration-Based Screening of Sliding and Rocking Potential for a Freestanding Disposal Canister Subjected to Floor Motions in a Repackaging Facility

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## 1. Introduction

In Korea, a deep geological disposal system is under development for the long-term isolation of spent nuclear fuel (SNF). Following on-site and interim storage, SNF will be transported to the disposal facility and transferred from storage canisters into disposal canisters before underground emplacement. The repackaging process comprises fuel transfer, canister sealing and inspection, and the subsequent transfer of the loaded and sealed disposal canisters to the underground emplacement area [1].

The Korea Radioactive Waste Agency (KORAD) is developing the KORea Advanced DIsposal System (KORADIS), which includes a conceptual design for a repackaging facility. Within the facility, empty disposal canisters are received and temporarily staged in the receiving zone, whereas loaded and sealed canisters are handled in the dispatch zone before being transferred to the underground repository [1]. This study considers a scenario in which a disposal canister remains unanchored and freestanding on the facility floor during temporary staging or between handling operations.

Previous studies of the seismic response of freestanding casks have focused primarily on aboveground dry-storage configurations, in which the casks are typically supported on concrete pads [2–5]. To the authors' knowledge, no previous study has evaluated the seismic stability of a freestanding disposal canister within a repackaging building. Whereas aboveground storage casks are excited at or near ground level, a canister within a building is subjected to floor motion modified by the dynamic response of the supporting structure. Accordingly, this study performs a preliminary seismic stability screening of a freestanding disposal canister using floor acceleration responses obtained from a seismic analysis of the conceptual repackaging facility.

## 2. Analysis Methodology

This section describes the structural time-history analysis used to obtain floor motions and the subsequent acceleration-based rigid-body screening used to evaluate the potential onset of sliding and rocking.

### *2.1 Structural model and seismic analysis of the repackaging facility*

The structural model of the repackaging facility was developed based on the KORADIS conceptual design and process description [6,7]. The facility comprises receiving and dispatch zones, with repackaging operations performed on the first floor. Fig. 1 shows the first-floor layout and potential locations for the temporary placement of disposal canisters. A three-dimensional finite-element model was developed using OpenSees [8], with the reinforced-concrete walls and slabs modeled using four-node ASDShellQ4 elements and LayeredShell sections [9].

Because the repository site has not yet been selected, site-specific seismic-hazard and geotechnical data were unavailable. Therefore, the horizontal and vertical design response spectra of U.S. Nuclear Regulatory Commission Regulatory Guide 1.60, Revision 2 (RG 1.60) [10], were adopted as target spectra for the preliminary site-independent analysis. The spectra were anchored to a horizontal peak ground acceleration of 0.1 g. Five spectrum-compatible, three-component artificial ground-motion sets, each consisting of two orthogonal horizontal components and one vertical component, were generated. The three components were simultaneously applied at the model base in direct-integration time-history analyses.

Absolute floor acceleration time histories were extracted at ten locations on the first-floor slab: two slab-center and eight near-wall locations, as shown in Fig. 1. At each location, 5%-damped floor response spectra (FRS) were calculated in the three translational directions. The median spectra obtained from the five

ground-motion sets are presented in Fig. 2. The dominant global modes with largest modal participation in the x, y, and z directions occurred at approximately 9.5, 5.2, and 14.5 Hz, respectively. Amplification was observed in all three directions, with pronounced local vertical peaks. Inspection of the mode shapes indicated that the vertical peaks at approximately 6.1 and 7.2 Hz in the western and eastern slabs, respectively, were associated with local out-of-plane slab modes rather than the dominant global vertical mode.

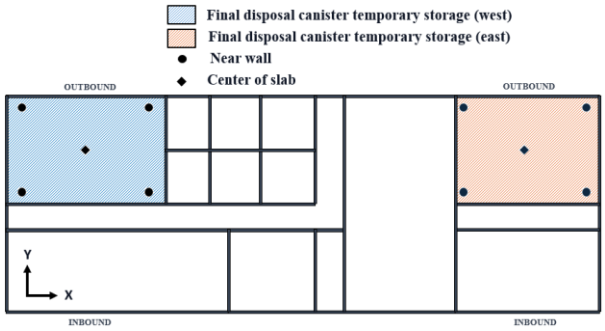



Fig. 1. First-floor structural layout and ten selected floor-response locations.

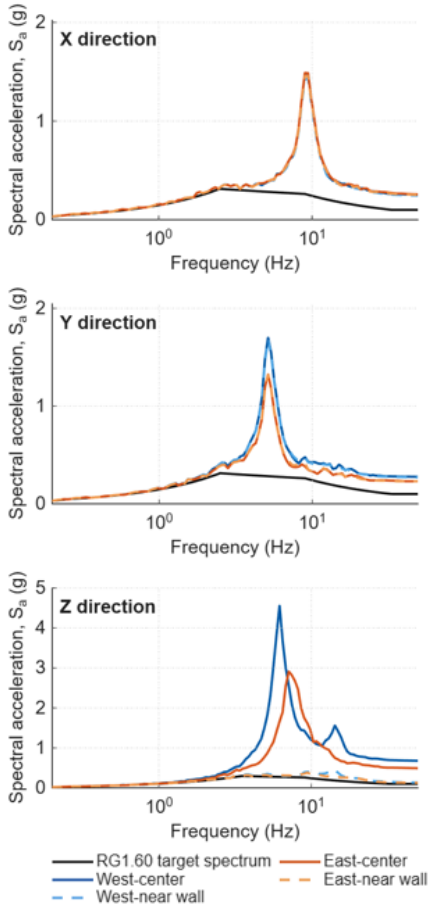



Fig. 2. Median 5%-damped floor response spectra at the selected locations, calculated from the five RG 1.60-compatible ground-motion sets.

### *2.2 Acceleration-based rigid-body stability screening of the disposal canister*

For preliminary screening, the unanchored disposal canister was idealized as a rigid, upright circular cylinder resting on a flat rigid floor. The XZ and YZ planes were evaluated independently to represent the two principal horizontal directions of the facility. Simultaneous horizontal and vertical absolute accelerations were evaluated at each time step so that the effect of vertical motion on the instantaneous sliding and rocking resistance could be retained. The reference geometry was based on the loaded SKB PWR canister [11], resulting in a geometric slenderness ratio of $\lambda = R/h = 0.217$, where R is base radius and h is the center-of-gravity height. Three canister-floor friction coefficients, $\mu = 0.20$, 0.50, and 0.80, were considered to examine the sensitivity of the governing instability mode to the interface condition.

Let $a_h(t)$ and $a_v(t)$ denote the horizontal and vertical floor accelerations, respectively, with upward vertical acceleration taken as positive. While contact is maintained, the effective gravity is $g + a_v(t)$. Accordingly, downward vertical acceleration reduces the normal force and restoring moment, whereas upward acceleration increases them. The instantaneous sliding- and rocking-onset indices were defined from force and moment equilibrium [12–14] as

$$I_s(t) = \frac{|a_h(t)|}{\mu[g + a_v(t)]} \tag{1}$$

$$I_r(t) = \frac{h|a_h(t)|}{R[g + a_v(t)]} \tag{2}$$

where $I_s > 1$ indicates exceedance of the frictional sliding threshold and $I_r > 1$ indicates exceedance of the rocking-onset threshold. Because both indices contain the same effective-gravity term, the governing mode is determined by the relationship between the friction coefficient and the geometric slenderness ratio: sliding governs when $\mu < \lambda$, rocking governs when $\mu > \lambda$. These criteria apply only while $g + a_v(t) > 0$; loss of contact is outside the scope of the present screening.

Each simultaneous acceleration pair was classified as no exceedance, sliding only, rocking only, or combined exceedance. The procedure was applied to the five input ground-motion sets and to the absolute floor acceleration histories obtained at the ten response locations. The resulting screening domains for the XZ and YZ directions are presented in Fig. 3. This procedure identifies threshold exceedance only; it does not simulate subsequent sliding, rocking, impact or overturning.

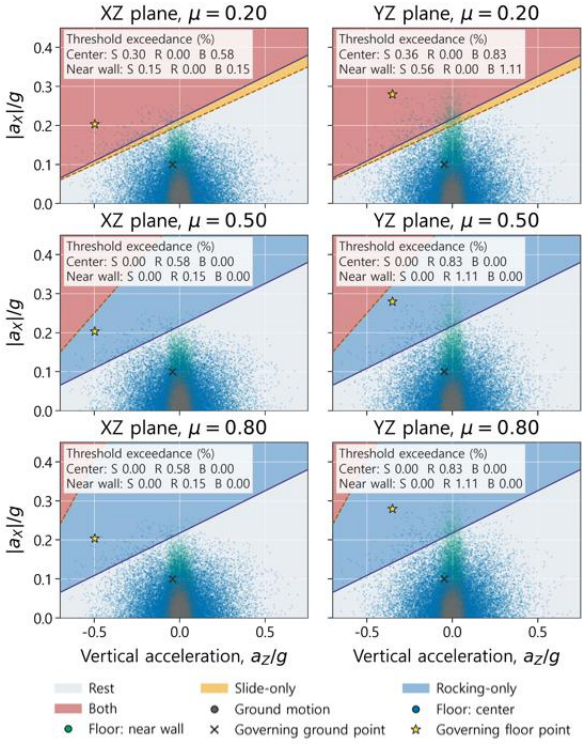



*Fig. 3. Acceleration-based screening of sliding and rocking onset in the XZ and YZ planes for three friction coefficients.*

### 3. Findings and Concluding Remarks

The input ground motions remained below both onset thresholds for all friction cases, whereas the first-floor responses exceeded the sliding and/or rocking thresholds at same locations. This difference resulted from structural amplification of the horizontal and vertical accelerations. In particular, downward vertical acceleration reduced the effective gravity g + $a_v(t)$, thereby lowering both the frictional resistance and restoring moment against rocking.

Only a small fraction of floor-acceleration pairs exceeded the onset thresholds, and the YZ direction was generally more critical than the XZ direction. In the low-friction case, the canister was more likely to reach the sliding limit, sometimes together with the rocking limit. In the higher-friction cases, rocking became the governing mode. This change is explained by the relationship between the friction coefficient and the slenderness of the canister. In the low-friction case, the sliding threshold governed, with some pairs also exceeding the rocking threshold. At higher friction levels, the rocking threshold governed, consistent with the relationship between μ and λ. At the most critical floor location, the maximum rocking index approached 2, compared with the onset threshold of 1

However, exceeding a screening limit does not show how much the canister moves or whether it overturns. The method identifies only the possible onset of motion; a dynamic analysis is required to determine the subsequent response. Nevertheless, screening based only on the input ground motion may miss threshold exceedances caused by floor amplification. The vertical floor acceleration should also be included because it can reduce the resistance to both sliding and rocking.

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