Hybrid Passive Seismic Protection Strategies of Rigid Blocks

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Abstract

Many valuable artifacts and sensitive equipment respond to base excitations in a manner similar to rigid blocks. The economic and cultural significance of these objects is often comparable to that of the buildings housing them. Consequently, safeguarding such items against seismic events has become a crucial focus within civil engineering, comparable to the protection of entire structures.
Over the years, numerous strategies have been proposed to enhance the seismic resilience of rigid block-like objects. These methods generally fall into two broad categories: (i) coupling the objects with external systems, either in parallel or series (1,2,3), and (ii) employing seismic isolation techniques (4,5,6). Both approaches encompass passive and active solutions. Examples include pendulum mass dampers and tuned mass dampers directly attached to the objects, as well as hybrid configurations combining these techniques. More recent studies have explored advanced mechanisms, such as tuned mass damper inerters and actively controlled systems, to improve performance under seismic excitation.

Seismic isolation, the second major category, has been extensively applied to a variety of structures, leveraging devices like curved surface sliders and lead rubber bearings. This approach has also been adapted to non-structural components, such as equipment and artifacts, with experimental evaluations demonstrating its effectiveness. Analytical investigations into the application of seismic isolation to rocking blocks began approximately two decades ago. Early studies addressed the basic effectiveness of base isolation, later expanding to include factors like eccentricity and sliding. Tall and slender structures, such as ancient columns, were also studied, leading to the development of more sophisticated analytical and numerical models.

This study aims to develop a hybrid control strategy that combines seismic isolation and external nonlinear systems. Specifically, the research focuses on analyzing the effectiveness of horizontal isolation techniques coupled with arrays of oscillators, such as hysteretic tuned mass dampers and/or impact oscillators.

The study rigorously derives equations of motion, uplift and impact conditions, assuming that the protected objects cannot slide but may undergo rocking motions. Horizontal isolation is modeled using a hysteretic system characterized by the Bouc-Wen model, while coupled oscillators are represented either by the same Bouc-Wen model or by an appropriate impact system model.

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Parametric analyses are performed using archetype objects subjected to recorded earthquake motions. The results, presented through rocking maps and overturning spectra, assess the performance of the proposed hybrid isolation approach. Comparisons with non-isolated systems further validate the findings and demonstrate the potential benefits of the combined methodology.

Acknowledgement This work is funded by the European Union - Next Generation EU, Mission 4 Component 2 Investment 1.1, in the framework of the project PRIN 2022, "2022TH5HC2 - Engineered basements for vibration protection of artworks and strategic sensitive equipment" (CUP: E53D2300373 0006, University of L'Aquila).

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