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Passive and hybrid mitigation of potential near-fault inner pounding of a self-braking seismic isolator

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ABSTRACT

A seismic isolated structure is usually a long-period structural system, which may encounter a low-frequency resonance problem when subjected to a near-fault earthquake that usually has a long-period pulse-like waveform. This long-period wave component may result in an enlargement of the base displacement and a decrease of the isolation efficiency. To overcome this problem, a rolling-based seismic isolator, referred to as roll-n-cage (RNC) isolator, has been recently proposed. The RNC isolator has a built-in buffer (braking) mechanism that limits the peak isolator displacements under severe earthquakes and prevents adjacent structural pounding. This paper addresses the problem of passive and hybrid mitigation of the potential inner pounding of the self-braking RNC isolator under near-fault earthquakes. Numerical results show that the RNC isolator can intrinsically limit the isolator displacements under near-fault earthquakes with less severe inner pounding using additional hysteretic damping and active control forces.

1. Introduction

In earthquake-prone areas, civil structures experience exceptional loading conditions that may result in wide undesirable losses and damage. Seismic isolation systems are essentially designed to preserve structural safety, prevent occupants' injury and properties' damage. The major concept in base isolation is to diminish the fundamental frequency of structural vibration to a value lower than the dominant energy frequencies of earthquake ground motions [1]. However, seismically isolated structures are expected to experience large displacements relative to the ground especially under near-fault (NF) earthquakes. The NF ground motions are characterized by one or more intense long-period velocity and displacement pulses, which lead to a large isolator displacement [2,3]. Such large displacements are accommodated by providing a sufficient seismic gap around the isolated structure. In some cases, the width of the provided seismic gap is limited due to practical constraints. Therefore, a reasonable concern is the possibility of pounding of seismically isolated structures with the surrounding adjacent structures during severe seismic excitations such as NF ground motion earthquakes.

Regarding pounding, significant research works have been reported for the case of conventional buildings, like for instance [4–9], where adjacent buildings are connected through damping devices. In the context of earthquake-induced pounding of base isolated structures, in [10], the author simulated the superstructure of an isolated building as a continuous shear beam in order to investigate the effects of pounding on structural response. A very high acceleration response was observed during pounding with the surrounding retaining wall at the isolation level. Similar work was done by Malhotra [11], where it was found that the base shear forces increase with the stiffness of the isolated structure or the surrounding retaining wall. The seismic response of multi-story building supported on various base isolation systems during impact with adjacent structures was studied by Matsagar and Jangid [12]. It was observed that superstructure acceleration increases with the increase of the isolation gap up to a certain value and then the acceleration decreases with further increase of gap, and the effects of impact are found to be severe for the system with flexible superstructure, increased number of stories and greater stiffness of the adjacent structure. In [13], the earthquake induced pounding in friction varying base isolated buildings was investigated. They found that the impact force is very high when the sliding friction coefficient is constant. However, the impact force is quite low when the friction coefficient is allowed to vary

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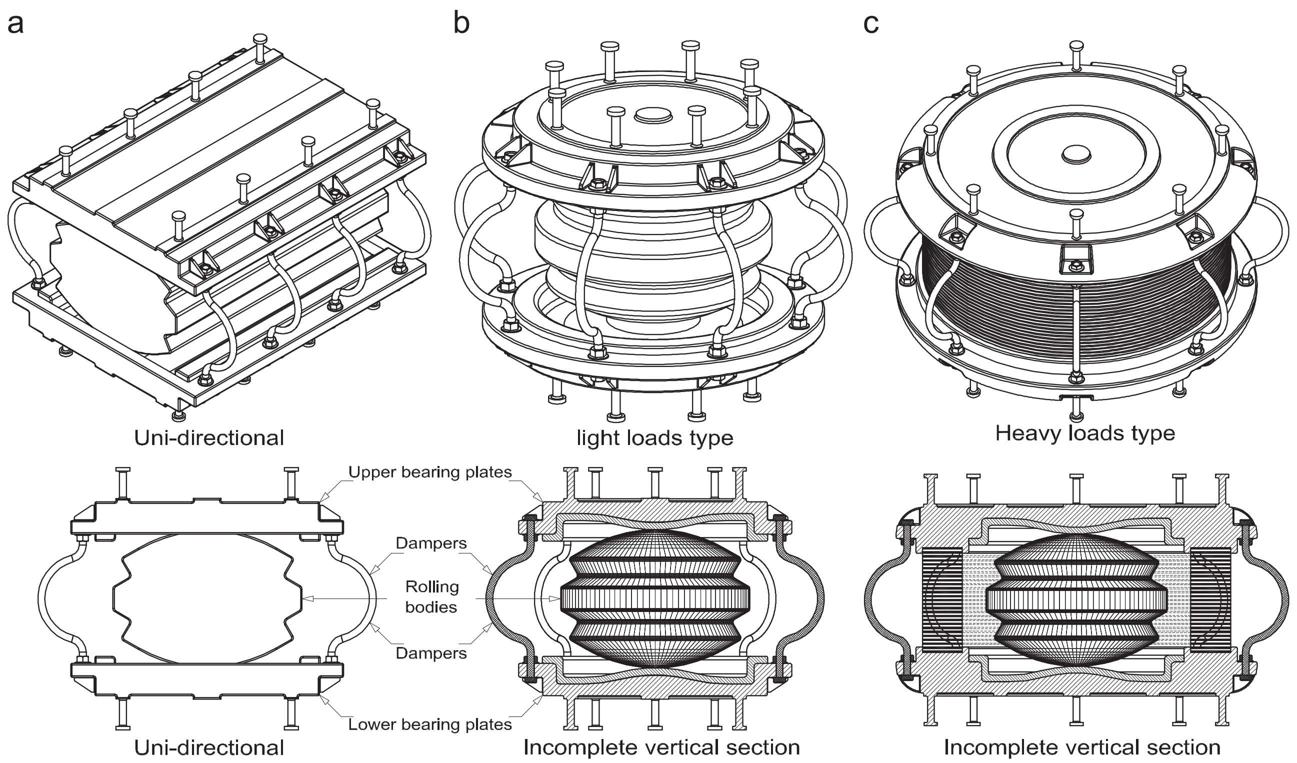

Fig. 1. The available forms of the RNC isolator : (a) unidirectional; (b) multidirectional for light to moderate structures; (c) multidirectional for heavy structures.

with velocity. Through parametric analysis, Komodromos et al. studied the effects of pounding of a seismically isolated building with the surrounding retaining wall [14,15], revealing the damaging effects of structural impact on the effectiveness of seismic isolation. The pounding of an isolated building with adjacent structures was studied in [16]. It was found that if a sufficient gap is provided, with which pounding with the surrounding moat wall at the base of the building could be avoided, this does not ensure that the building will not eventually collide with neighboring buildings due to the deformations of their superstructures.

A new seismic isolation device, called roll-n-cage (RNC) isolator, has been recently proposed in [17–20]. Fig. 1 illustrates three possible typical configurations, where essentially a rolling body with a special quasi-elliptical geometry is nested between two upper and lower plates. The RNC isolator provides in a single unit all the necessary functions of rigid support, horizontal flexibility with enhanced stability and energy dissipation characteristics, in addition to an integrated buffer mechanism. This mechanism is built by a proper geometric design of the rolling body and the lower and upper plates, as shown in Fig. 2. The two main advantages of incorporating the buffer mechanism into the RNC isolator are as follows:

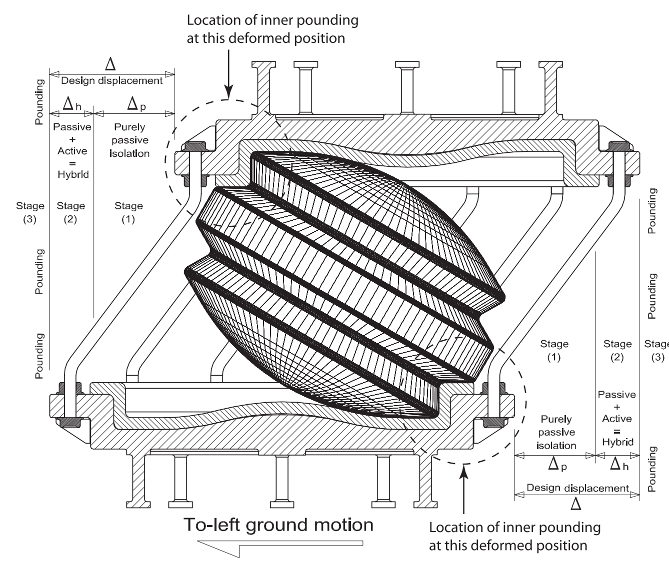

Fig. 2. The integrated buffer mechanism of the RNC isolator.

1. To limit the base displacement under severe earthquakes stronger than the design earthquake. This helps avoiding large unrecoverable base displacements.
2. To restrict the potential pounding (if any), under severe earthquakes, within the RNC isolator bounds. This aims to keep the adjacent structural pounding away from happening in order to minimize or even avoid the very likely damage due to structural pounding.

The above second advantage may require the price of internal shocks between parts of the isolator, see Fig. 2. This paper is concerned with analyzing and mitigating the severity of such shocks and investigating their influence in the effectiveness of the RNC device for achieving a satisfactory structural isolation.

The approach proposed in this paper for reducing the internal pounding is twofold: first, by using purely passive means, and second by adding feedback active control forces. In the passive mode, the paper investigates the ability of the provided damping mechanism of the isolator, by means of metallic hysteretic dampers arranged around the rolling body as seen in Fig. 1, to reduce the bearing displacement to be within affordable limits to avoid pounding. In the active mode, the paper proposes the application of a supplementary active force to control (reduce) the isolated base displacement just before attaining the design bearing displacement (Δ in Fig. 2) to reduce the possibility of pounding and its effect on