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Review article

A review of rolling-type seismic isolation: Historical development and future directions

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ABSTRACT

Rolling-type base isolation as a means of earthquake protection is over a century old but has advanced rapidly in recent years due to an increase in research interest. Significant developments in modeling and testing of rolling-type isolators have expanded our understanding and acceptance of this concept. This paper reviews some of the history of rolling-type isolation, as well as recent research activity focused on high-performance approaches and novel applications. Future research topics have also been identified, such as innovations to increase displacement capacity and decrease displacement demands.

Contents

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1. Introduction

Vibration isolation is a design strategy based on the premise that an object can be uncoupled or *isolated* from harsh disturbances, thereby protecting the object from damaging effects [1]. By effectively shifting the natural frequency of the isolated object, transmitted vibrations and forces are attenuated. The introduction of damping in the isolator layer is beneficial in decreasing deformations across the isolator, at the expense of reducing the isolation performance. Applications in buildings, bridges, etc. involve introducing a flexible or compliant interface between the base of the structure and the ground. The flexible mounting can take a wide range of forms [2], e.g., elastomeric bearings, rocking systems, coil springs, and rollers/ball bearings. Refs. [3,4] review recent advances in seismic isolation devices, but this paper focuses specifically on rolling-type isolation systems.

1.1. Brief history

Rolling-type base isolation dates back to the 19th century. In 1870, Jules Touaillon was granted a patent for an isolation system comprised of a rolling ball contained in counter-facing spherical recessed surfaces [5], as shown in Fig. 1(a). Soon thereafter, patents were granted for similar concepts, e.g., Seiler in 1907 [6], Schär in 1910 (Fig. 1(b)) [7], Cummings in 1930 [8], and Bakker in 1935 [9]. The basic theory behind these patents, as well as the modern incarnations (e.g., Kemeny in 1997 [10]), is remarkably simple, making this an attractive concept for practice.

1.2. Basic theory

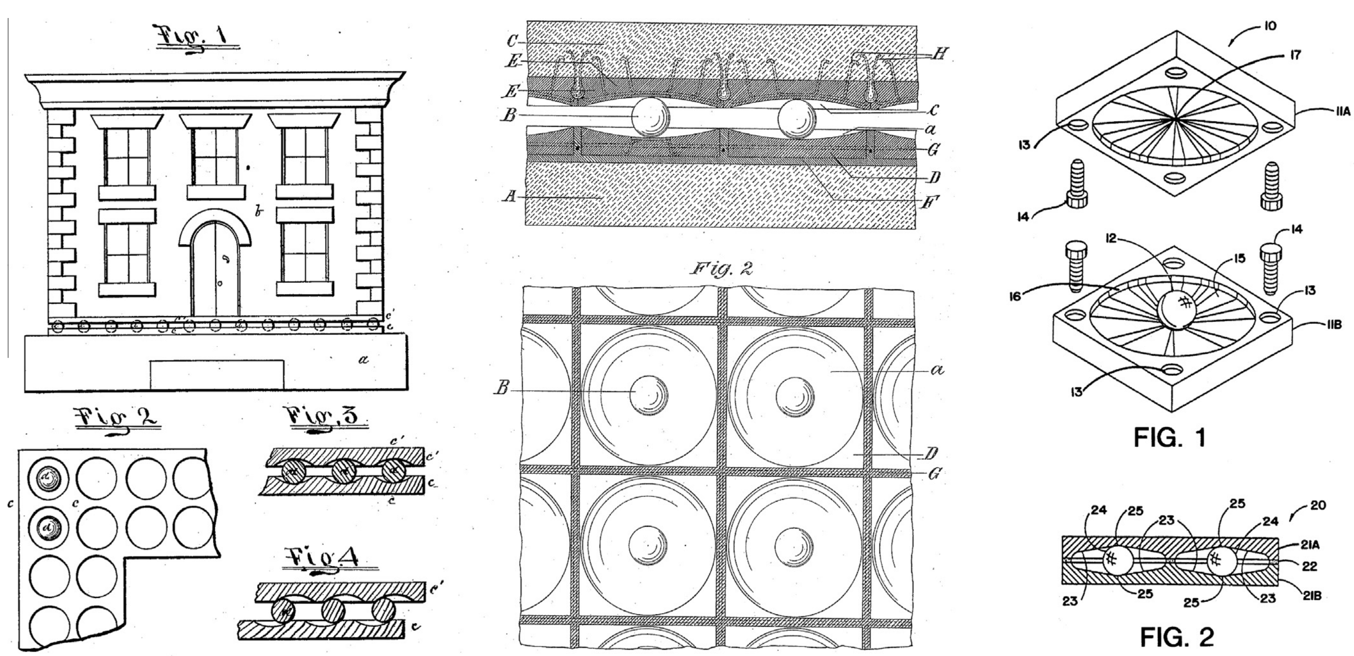
The basic elements of a rolling-type isolation system (RIS) are: (i) counter-facing concave bearing (or rolling) surfaces and (ii) a ball interposed therebetween. Cylindrical rollers are sometimes used instead of balls [8], constraining motion to be in only one direction. Relative motion across the bearing produces a change in potential energy, which creates a natural re-centering effect much like a pendulum – hence the common name "rolling pendulum-type isolator." The restoring or re-centering force is mass proportional, and the natural period of the isolator is independent of the mass of the object being isolated – unlike a spring-based isolation device.

The shape of the rolling surfaces dictates the displacement-dependent restoring force. The two predominant shapes in practice are spherical [5] and conical [10,11]. Gravitational restoring forces are not produced when flat rolling surfaces are used [12]. So, re-centering forces must be generated by some other means to ensure residual displacements are sufficiently small. Various techniques have been proposed: an added counterweight [12], traditional spring [13,14], elliptical rods [15], and eccentrically-pinned rollers [16,17].

A large amount of research on RISs has been performed in the past quarter century. In this paper, the primary applications of RISs in the field of earthquake engineering – buildings, bridges, and equipment – will first be reviewed (Section 2). Then, an overview of recents model development and experimental testing (validation) will be discussed (Sections 3 and 4), followed by a review of concepts to introduce supplemental damping (Section 5). Finally, future research directions identified through this state-of-the-art review will be outlined and discussed (Section 6).

2. Applications of rolling-type isolation

Rolling-type seismic isolation was originally proposed as a means of protecting building superstructures – as reflected in the titles of early patents, e.g. "Improvement of buildings" [5] and "Foundation for buildings" [6,7]. Even though rolling-type isolation predates other seismic isolation concepts – e.g., sliding-type bearings and elastomeric bearings – research and practice was slower to develop and mature. To the best of the authors' knowledge, the earliest research article on rolling isolation was by Lin and Hone in 1993 [12], which focused on protection of structures (buildings). Since then, much work has been put into assessing the performance of RISs for applications for buildings, as well as



(a) (b) (c)

Fig. 1. Early patents for rolling-type isolation: (a) Touaillon [5], (b) Schär [7]. (c) Ball-in-cone seismic isolation bearing patented by Kemeny [10].