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Original

Seismic isolation of structures. Part I: Concept, review and a recent development

Aislamiento sísmico de estructuras. Parte I: concepto, revisión y evolución reciente

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Abstract

This paper is the first of two companion papers on seismic isolation of structures. Those two papers present the topic since its fundamental concepts; passing through its development history and comparisons of developed isolation systems over time; up to addressing one of the most recent isolation devices, besides a detailed case study of its implementation under severe near-fault earthquakes considering closely-spaced asymmetric multistory structures. The present paper, Part I, introduces briefly the concept of seismic isolation and its development history. Then presents for an application using a recently proposed seismic isolation systems named Roll-in-Cage (RNC) isolator. The objective of the second companion paper, Part II, is to minimize twist of isolated asymmetric structures, together with their torsional pounding with adjacent structures, considering insufficient seismic gaps and strong near-fault ground motions, by means of the RNC isolator.

Keywords: Seismic isolation; Concept; History; Asymmetric structures; Pounding; Roll-in-Cage isolator

Resumen

Este artículo es el primero de dos artículos complementarios sobre aislamiento sísmico de estructuras, que presentan el tema desde sus conceptos básicos, pasando por la historia de su desarrollo y las comparaciones de sistemas de aislamiento desarrollados a lo largo del tiempo, hasta abordar uno de los dispositivos de aislamiento más recientes, además de un caso práctico detallado de su implementación en condiciones de terremotos intensos cerca de la falla con la valoración de estructuras asimétricas de varios pisos con poco espacio entre sí. El presente artículo, la parte I, presenta brevemente el concepto de aislamiento sísmico y la historia de su desarrollo. Luego se presenta una aplicación que utiliza un sistema de aislamiento sísmico propuesto recientemente, denominado aislador *roll-in-cage* (RNC). El objetivo del segundo artículo complementario, la parte II, es reducir la torsión de estructuras asimétricas aisladas, así como el golpeteo torsional con estructuras adyacentes, considerando los casos de espacio insuficiente entre las estructuras y de fuertes movimiemtos sísmicos por proximidad a una falla, por medio del aislador RNC.

Palabras clave: Aislamiento sísmico; Concepto; Historia; Estructuras asimétricas; Golpeteo; Aislador *roll-in-cage*

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1. Introduction

Seismic base isolation has been used with increasing popularity to protect structures, together with their occupants, secondary systems and internal equipment, from the damaging effects of earthquakes. This paper addresses such popular protection strategy, against devastating seismic events, through three steps: highlighting its fundamental concepts; reviewing briefly its development history; and giving a challenging application example of seismic isolation into closely spaced asymmetric buildings using the recent RNC isolator.

2. Philosophy behind seismic isolation

Seismic isolation is a design strategy based on the premise that it is both possible and feasible to uncouple a structure from the ground and thereby protect it from the damaging effects of the earthquake motions. To achieve this result, while at the same time satisfying all of the in-service functional requirements, additional flexibility is introduced usually at the base of the structure. Additional damping is also provided to control the deflections, which occur across the isolation interface.

Decoupling a structure from the horizontal components of a ground motion gives the structure a fundamental frequency that is much lower than its fixed-base frequency and the predominant frequencies of the ground motion. The first dynamic mode of the isolated structure involves deformation only in the isolation system; the structure above is being to all intents and purposes rigid. The higher modes that produce deformation in the structure are orthogonal to the first mode, and consequently, to the ground motion. These higher modes do not participate in motion, so that the high energy in the ground motion at these higher frequencies cannot be transmitted to the structure. The isolation system does not absorb the earthquake energy, but rather deflects it through the dynamics of the system; this effect does not depend on damping, but a certain level of damping is beneficial to suppress possible resonance at the isolation frequency.

Based on fundamental vibration period perspective, an insight into the benefits of using base isolators in structures can be gained by considering the special case of a single-story linear undamped structure, which is separated from the ground by flexible bearings of lateral linear stiffness k_b as shown in Fig. 1(a). The bearings are connected together through a base mass, which is a rigid horizontal diaphragm of mass m_b just above the bearings. The whole system is idealized as a 2DOFs spring-mass system as shown in Fig. 1(b). The governing equations of motion are

$$m_b\ddot{y} + k(y_1 - y_2) + k_b(y_1 - x_2) = 0 \quad (1a)$$

$$m\ddot{y}_2 + k(y_2 - y_1) = 0 \quad (1b)$$

where m is the main mass, k is the stiffness of the structure above the isolator and y_1 and y_2 are the total displacements of the base and the main masses, respectively. If the relative displacements between the masses and the supports are defined to be

$$x_1 = y_1 - x_g \quad (2a)$$

$$x_2 = y_2 - x_g \quad (2b)$$

It then follows from substituting Eq. (2) into Eq. (1) that

$$m_b\ddot{x}_1 - kx_2 + (k + k_b)x_1 = -m_b\ddot{x}_g \quad (3a)$$

$$m\ddot{x}_2 + kx_2 + kx_1 = -m\ddot{x}_g \quad (3b)$$

Consider the special case where m_b is very small and so is assumed zero. Therefore, Eq. (3a) becomes

$$-kx_2 + (k + k_b)x_1 = 0 \quad (4)$$

Solving for x_1 in terms of x_2 in Eq. (4) gives

$$x_1 = \left(\frac{k}{k + k_b}\right)x_2 = \left(\frac{1}{1 + (k_b/k)}\right)x_2 \quad (5)$$

The displacement x_1 is the displacement of the base isolator relative to the ground. Eq. (5) gives the value of x_1 in terms of x_2 and the ratio of the isolator stiffness to that of the structure. Note that if k_b goes toward infinity (i.e. very stiff bearing), then x_1 goes toward zero. In addition, if k_b is equal to k, then x_1 is equal to one-half of x_2. The ideal, or perfect, isolation case is attained if k_b goes toward zero. In this case, $x_1 = x_2$ which translates into zero story drift, perfect rigid-body vibration of the structure and full structure-ground separation in the horizontal direction. Substituting Eq. (5) into Eq. (3b) gives the equation of motion for this spring-mass system as

$$m\ddot{x}_2 + \left[1 - \left(\frac{1}{1 + (k_b/k)}\right)\right]kx_2 = -m\ddot{x}_g \quad (6)$$

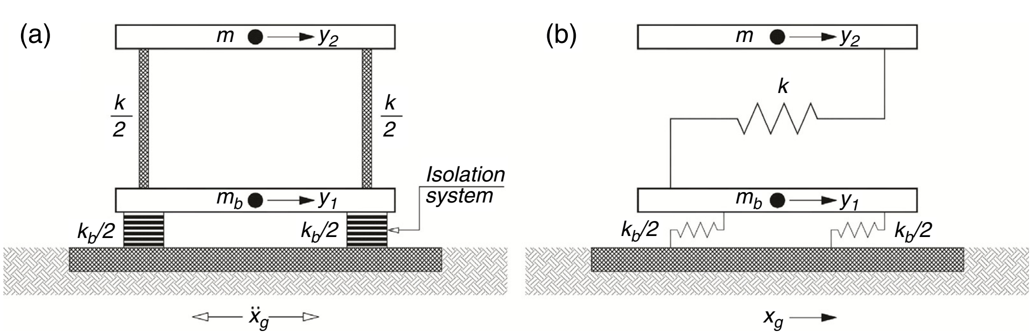

Figure 1. Single story base-isolated structure.

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