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Multi-unit rolling isolation system arrays: Analytical model and sensitivity analysis

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ABSTRACT

Rolling isolation systems (RISs) have been used extensively to protect vibration-sensitive equipment, such as server cabinets, from earthquake-induced floor motions. These systems are commonly installed in multi-unit arrays to isolate multiple cabinets from harsh floor motions. The mathematical model presented in this paper is an extension of an experimentally-validated model for a single-unit RIS and is amenable to an arbitrary number of isolated cabinets. The proposed model is first compared to free response tests and is then validated with forced response tests using a synthetic waveform representative of earthquake-induced floor motions. An extensive numerical parameter study using the proposed model is carried out to assess the influence of the number of isolated cabinets, as well as mass eccentricity, on the seismic isolation performance of these systems. Through an incremental dynamic analysis it is shown that systems with more cabinets are less prone to impacts, indicating better performance. Rotations produced in the presence of mass eccentricity may induce premature impacts transverse to the loading direction diminishing these systems' performance.

1. Introduction

Rolling isolation systems (RISs) have been used extensively to protect structures and nonstructural components from earthquake-induced ground and floor motions. The protected object is mechanically decoupled from horizontal components of ground motions via a rolling interface. Recently, there have been many studies of RISs, with applications ranging from bridges [1–5], to buildings [6–12], to floors within a building [13,14], and to individual objects inside a building [15–21]. RISs are widely used to isolate mission-critical equipment (e.g., server cabinets, mainframes, LAN racks, electronics enclosures, and telecommunications switches) and valuable property. The prediction of the response of equipment isolation systems and their ability to protect building contents requires models that can capture the observed nonlinear behavior of actual RISs subjected to multi-axial loading.

Previous efforts to model RISs have focused on isolating a single cabinet or piece of equipment [18,22]. However, multiple cabinets commonly need to be protected. Common practice is to install a multi-unit row or *array* of RISs to support and isolate a cluster of cabinets, as shown in Fig. 1. In doing so, additional bearings (beyond the typical four) must be incorporated to support the added load. Because the subunits are installed in a row, the overall length and aspect ratio of the isolation system change. The displacement across the end bearings due to rotation is proportional to overall length of the RIS, making the multi-unit system more vulnerable to rotations. RISs are known to rotate even in the absence of rotational disturbances due to their chaotic nature and the nonholonomic ball dynamics [18]. These rotations can be exacerbated if the equipment mass is not concentric with the center of stiffness.

In this paper, the equations of motion of multi-unit RIS arrays are derived, incorporating the rolling dynamics of the balls and an arbitrary number of isolated cabinets and mass eccentricity. The resulting mathematical model is used to numerically assess the influence of the number of isolated cabinets and mass eccentricity on the performance of multi-unit RIS arrays subjected to floor motions representative of a range of operating conditions. Isolation performance is characterized by the peak total acceleration experienced by the isolated cabinets, which are compared to a representative threshold for electrical equipment.

2. Description of the model and modeling assumptions

Consider the multi-unit RIS array illustrated in Fig. 2. Vibration-sensitive equipment, such as electrical cabinets, are rigidly connected to the top frame, and the top frame and equipment are mechanically isolated from the bottom frame via *rolling bearings*. Each rolling bearing is composed of a large, steel ball that rolls between a concave-up lower

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Fig. 1. Multi-unit rolling isolation system array installation at a financial institution data center.
Source: [23].

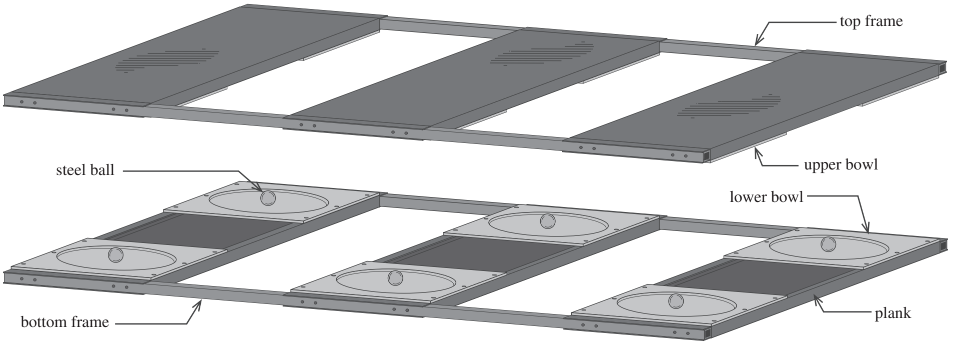

Fig. 2. Configuration of an RIS array. The payload mass is carried by the top frame which is supported at various points by steel balls between counter-facing concave bowls. The bottom and top frames isolate groups of equipment from harsh floor motions.

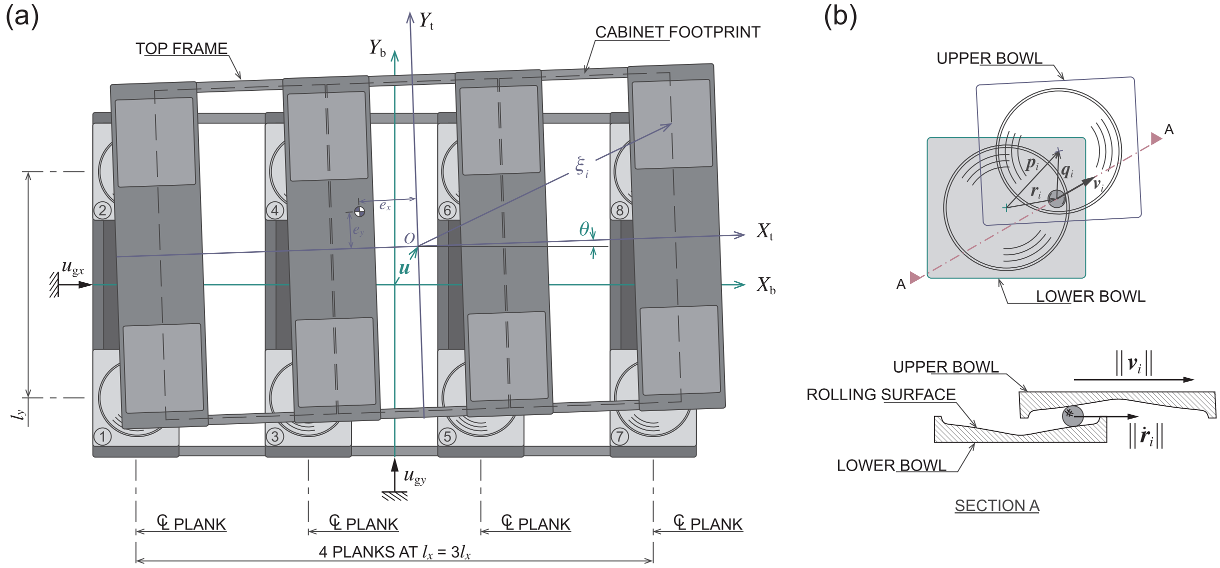

Fig. 3. Geometry and notation of a rolling isolation system, $N = 3$: (a) displaced configuration and (b) kinematics of rolling balls.

bowl and a concave-down upper bowl. The bearings are configured in pairs on planks that are connected together with steel bars. For a single isolated cabinet, only two planks (four bearings) are required. For N pieces of equipment, $N + 1$ planks are required; e.g., three planks for two cabinets (Fig. 2).

2.1. Geometry and notation

Consider the displaced configuration of the RIS illustrated in Fig. 3. The bearings are numbered $i = 1, \ldots, n$, where the number of bearings, n, depends on the number of isolated cabinets, N; i.e., $n = 2(N + 1)$. The X_t–Y_t coordinates of the ith bowl center are given by $\boldsymbol{\xi}_i = \{x_i, y_i\}_t^{\mathsf{T}}$,[1] which is dictated by the frame geometry. The planks are spaced at l_x on centers, with the bearings spaced at l_y on centers.

The N isolated cabinets are assumed to be identical, each having a mass m that is eccentrically located at (e_x, e_y) relative to centroid of the

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[1] In this paper, vectors are represented by boldface minuscule letters, and matrices by majuscule letters; the superscript ‘T’ denotes the transpose; and the subscripts ‘t’ and ‘b’ are used to indicate the coordinate system in which positions are measured, namely top (X_t, Y_t) and bottom (X_b, Y_b).