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On the effect of near-field excitations on the reliability-based performance and design of base-isolated structures

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ABSTRACT

This work explores the effect of near-field excitations on the reliability-based performance and design of base-isolated systems. In particular base-isolated buildings under uncertain excitation are considered in this work. A probabilistic logic approach is adopted for considering the variability of future excitations. Isolation elements composed by rubber bearings are used in the present formulation. The non-linear behavior of the bearings is characterized by a biaxial hysteretic model which is calibrated with experimental data. The performance of the isolated system is defined in terms of the isolators deformations and the superstructure interstory drifts and absolute accelerations. First excursion probabilities are used as measures of system reliability. Two example problems involving large finite element building models are presented to illustrate the ideas set forth.

1. Introduction

The recent improvements in isolation system products have led to the design and construction of an increasing number of seismically isolated structures worldwide [1–4]. Similarly, seismic isolation has been extensively used for seismic retrofitting of existing buildings [5,6]. In addition, base isolation concepts are utilized for the protection from shock and vibration of sensitive components of critical facilities such as hospitals, nuclear reactors, industrial and data center facilities. One of the difficulties in the analysis and design of base-isolated systems has been the explicit consideration of the non-linear behavior of the isolators. Another challenge has been the efficient prediction of the dynamic response under future ground motions considering their potential variability as well as the efficient control of competing objectives related to the protection of the superstructure and the minimization of the base displacement. In particular, the response of this class of systems under near-field ground motions has been recognized to be one of the current challenges for the analysis and design of base-isolated systems. In fact, the study of the effects of near-field ground motions on engineering structures is an active research topic in earthquake engineering [7–10]. Near-field ground motions frequently include a strong long period pulse that has important implications for flexible structures such as base-isolated systems. For these systems near-field ground motions may lead to excessive base deformations and superstructure deformations with important implications for the integrity of the combined structural system (isolation system and superstructure).

The current work presents a framework for studying the effect of near-field excitations on the reliability-based performance and design of base-isolated systems. In particular, the case of large scale building models is considered in this work. The proposed study explicitly takes into account all non-linear characteristics of the combined structural system, and the variability of future excitations including near-field ground motions. Isolation systems composed by rubber bearings are used in the present formulation. The non-linear behavior of these devices is characterized by a biaxial hysteretic model which is calibrated with experimental data. A probabilistic logic approach is adopted for addressing the variability of future excitations. In the approach, probability is interpreted as a means of describing the incomplete information about the problem under consideration. This is established by characterizing the relative plausibility of future excitations by probabilistic models. A realistic stochastic model for the description of ground motions with high and low frequency components is considered in this work [11]. The model, which belongs to the class of point-source models, establishes a nexus between the knowledge about the characteristics of the seismic hazard in the structural site and future ground motions. First excursion probabilities are used as measures of the system reliability. In this setting, reliability is quantified as the probability that the response quantities of interest (base displacements and superstructure

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interstory drifts and absolute accelerations) will not exceed acceptable performance bounds within a particular reference period. Such probabilities are estimated by an adaptive Markov Chain Monte Carlo procedure [12].

In summary the novelty of this work is based on the integration of several independent tools in order to evaluate the effect of near-field excitations on the reliability-based performance and design of base-isolated systems. In particular, the following tools are integrated into the proposed methodology: a realistic stochastic model for the description of near-field ground motions; an accurate model for the nonlinear behavior of the isolators; and an advanced simulation technique for estimating high dimensional probability integrals. These tools allow to study the effect of near-field excitations on seismic isolated systems in a stochastic setting, e.g. from a reliability point of view.

The organization of the paper is as follows. Section 2 introduces the structural model for the superstructure and base platform. The stochastic model for the excitation is examined in Section 3. Section 4 deals with the characterization of the isolator elements. The reliability assessment and the structural response of base-isolated buildings are discussed in Sections 5 and 6, respectively. The effect of near-field excitations on the reliability-based performance and design of two large finite element building models are presented in Sections 7 and 8. The paper closes with some final remarks.

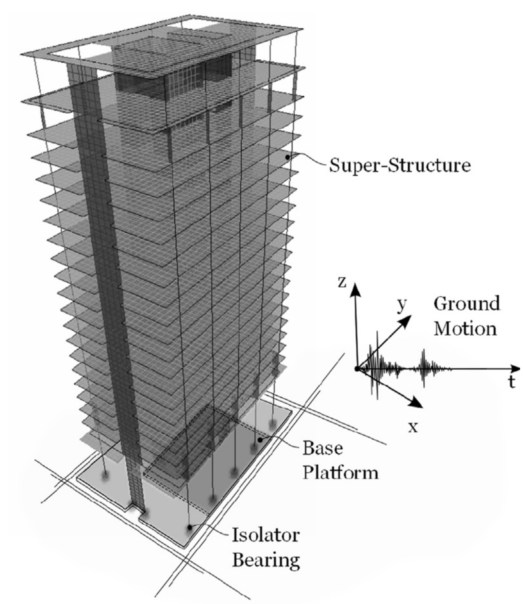

Fig. 1. Schematic representation of a base-isolated finite element building model.

2. Structural model

Finite element building models with a large number of degrees of freedom are considered for modeling the superstructure, i.e. the structure above the isolation system. For illustration purposes a schematic representation of a base-isolated finite element building model is shown in Fig. 1. The corresponding base platform with isolators is illustrated in Fig. 2. In general, base-isolated buildings are designed such that the superstructure remains elastic. Hence, the superstructure is modeled as a three dimensional linear elastic system while the base is assumed to be rigid in plane and it is modeled using three degrees of freedom as indicated in Fig. 2. Let $\mathbf{u}_s(t)$ be the nth dimensional vector of relative displacements of the superstructure with respect to the base, and $\mathbf{M}_s$, $\mathbf{C}_s$, $\mathbf{K}_s$ be the corresponding mass, damping and stiffness matrices. Also, let $\mathbf{u}_b(t)$ be the vector of base displacements with three components and $\mathbf{G}_s$ be the matrix of earthquake influence coefficients of dimension $n \times 3$, that is, the matrix that couples the excitation components of the vector $\ddot{\mathbf{u}}_g(t)$ to the degrees of freedom of the superstructure. The equation of motion of the superstructure is expressed in the form

$$\mathbf{M}_s\ddot{\mathbf{u}}_s(t)+\mathbf{C}_s\dot{\mathbf{u}}_s(t)+\mathbf{K}_s\mathbf{u}_s(t)=-\mathbf{M}_s\mathbf{G}_s[\ddot{\mathbf{u}}_b(t)+\ddot{\mathbf{u}}_g(t)] \tag{1}$$

where $\ddot{\mathbf{u}}_b(t)$ is the vector of base accelerations relative to the ground. To complete the formulation of the combined model, the equation of motion for the base platform is written as follows:

$$(\mathbf{G}_s^T\mathbf{M}_s\mathbf{G}_s+\mathbf{M}_b)(\ddot{\mathbf{u}}_b(t)+\ddot{\mathbf{u}}_g(t))+\mathbf{G}_s^T\mathbf{M}_s\ddot{\mathbf{u}}_s(t)$$
$$+\mathbf{C}_b\dot{\mathbf{u}}_b(t)+\mathbf{K}_b\mathbf{u}_b(t)+\mathbf{f}_{is}(t)=\mathbf{0} \tag{2}$$

where $\mathbf{M}_b$ is the mass matrix of the rigid base, $\mathbf{C}_b$ is the resultant damping matrix of viscous isolation components, $\mathbf{K}_b$ is the resultant stiffness matrix of linear elastic isolation components, and $\mathbf{f}_{is}(t)$ is the vector containing the nonlinear isolation elements forces. Rewriting the previous equations, the combined equation of motion of the base-isolated structural system can be formulated in the form

$$\begin{bmatrix} \mathbf{M}_s & \mathbf{M}_s\mathbf{G}_s \\ \mathbf{G}_s^T\mathbf{M}_s & \mathbf{M}_b+\mathbf{G}_s^T\mathbf{M}_s\mathbf{G}_s \end{bmatrix} \begin{Bmatrix} \ddot{\mathbf{u}}_s(t) \\ \ddot{\mathbf{u}}_b(t) \end{Bmatrix} + \begin{bmatrix} \mathbf{C}_s & \mathbf{O} \\ \mathbf{O} & \mathbf{C}_b \end{bmatrix} \begin{Bmatrix} \dot{\mathbf{u}}_s(t) \\ \dot{\mathbf{u}}_b(t) \end{Bmatrix}$$
$$+\begin{bmatrix} \mathbf{K}_s & \mathbf{O} \\ \mathbf{O} & \mathbf{K}_b \end{bmatrix} \begin{Bmatrix} \mathbf{u}_s(t) \\ \mathbf{u}_b(t) \end{Bmatrix} = -\begin{bmatrix} \mathbf{M}_s\mathbf{G}_s \\ \mathbf{M}_b+\mathbf{G}_s^T\mathbf{M}_s\mathbf{G}_s \end{bmatrix} \ddot{\mathbf{u}}_g(t) - \begin{Bmatrix} \mathbf{0} \\ \mathbf{f}_{is}(t) \end{Bmatrix} \tag{3}$$

It is noted the above formulation can be extended to other cases as well, for example the consideration of nonlinear models for the superstructure.

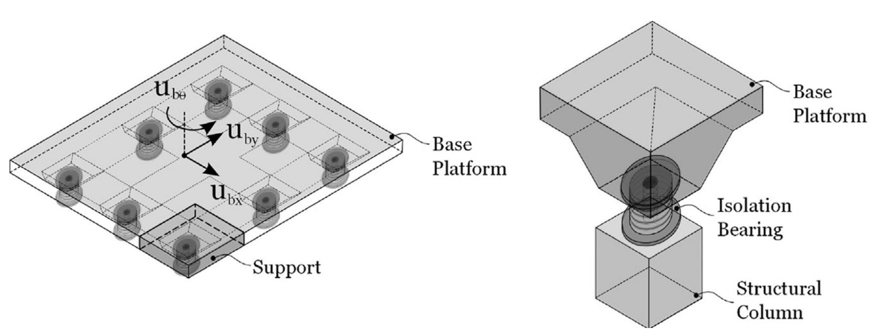

Fig. 2. Base platform with isolators.