Engineering Structures 172 (2018) 629–643

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Stochastic response of structures with hybrid base isolation systems

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ARTICLE INFO

Keywords:
Stochastic response
High damping rubber bearings
Low friction sliding bearings
Hybrid base isolation system
Trilinear hysteretic model
Nonlinear response
Monte-Carlo simulations

ABSTRACT

In 2004, two R/C residential buildings were retrofitted by using a hybrid base isolation system in Solarino, Sicily, and subsequently five free vibration tests were carried out in one of these buildings. The hybrid base isolation system combined high damping rubber bearings with low friction sliders. In terms of numerical modeling, a single-degree-of-freedom system is developed here with a new five-parameter trilinear hysteretic model for the simulation of the high damping rubber bearing, coupled with a Coulomb friction model for the simulation of the low friction slider. Furthermore, a shear beam type, four-degree-of-freedom model is used to numerically simulate the superstructure. Next, experimentally obtained data from the five initial-displacement, free vibration tests were used for the calibration of this six-parameter model describing the base isolation system. Following up on the model development, the present study employs Monte-Carlo simulations in order to investigate the effect of the unavoidable variation in the values of the six-parameter mechanical model on the response of both the hybrid base isolation system and the superstructure comprising the Solarino building. The calibrated parameters values from all the experiments are used as mean values, while the standard deviation for each parameter is deduced from the identification tests employing best-fit optimization for each experiment separately. The results of the Monte-Carlo simulations show that variation in the material parameters of the base isolation system produce a nonstationary effect in the response, which can be traced by the time evolution of its mean and standard deviation as computed from the response at different time instants. In addition, there is a magnification effect, since the coefficient of variation of the response, for most of the parameters, is larger than the coefficient of variation in the parameter values. The high level of nonlinearity in the base isolation system, as observed in the amplitude of vibration brought about by large initial displacements, helps explain the previously mentioned effects.

1. Introduction

Base isolation has been extensively used over the last decades for the protection of structures against earthquakes. The concept behind base isolation is the introduction of a flexible layer between the superstructure and its foundation [1]. The goal of base isolation is simply to reduce the transmission of energy from the ground to the superstructure [2]. To this end, the mechanics behind an isolation system are: (i) a flexible support in order to elongate the natural period of the structure, (ii) energy dissipation in order to control the relative displacements and (iii) sufficient rigidity under service loads (wind, minor earthquakes, ambient vibrations) to avoid unnecessary motion [3]. The first mode of an isolated structure involves only deformations in the base isolation level, while the higher modes do not contribute to the response due to orthogonality conditions [4].

The first systematic efforts for Italian buildings to be retrofitted with base isolation started in 2004, [5]. Among those buildings were two four-story R/C residential buildings in Via Baden Powell 23–25, Solarino, Eastern Sicily, [6]. The retrofit included a hybrid base isolation system, which combined 12 high damping rubber bearings with 13 low friction sliding bearings, [6]. In July 2004, static and dynamic tests were performed in one of the two Solarino buildings, see Fig. 1. The static tests were used for the identification of the static friction force, while the dynamic ones were in the form of free vibration tests following application and instantaneous release of a displacement close to the design value, [7]. More specifically, the identified initial displacements vary from 86 mm to 113 mm. The basic set-up for the free vibration tests is shown in Fig. 2. A hydraulic jack is supported at one end against a rigid wall, while at the other end supports a device which pushes against the base of the isolated building. The device is designed in such a way so as to transform into a mechanism at a specific force and release the building. The idea behind the design of this device is based on the articulated quadrilateral mechanism.

In the years following these experiments, research efforts were

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https://doi.org/10.1016/j.engstruct.2018.06.051
Received 17 October 2017; Received in revised form 12 June 2018; Accepted 14 June 2018

Fig. 1. One of the Solarino buildings in Via Baden Powell 25, Solarino, Sicily.

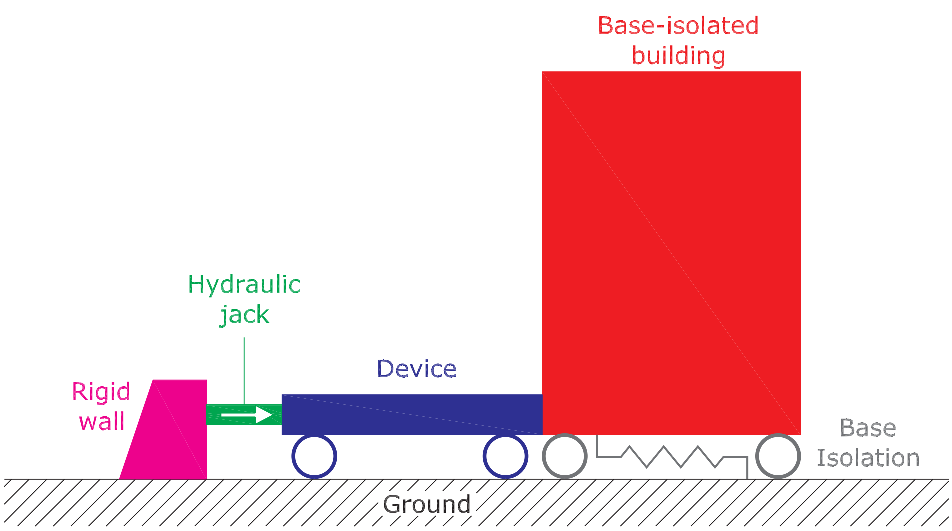

Fig. 2. Section view of the basic set up of the free vibration tests.

made towards dynamic identification of the Solarino hybrid base isolation system by using several mechanical models and various identification techniques. In [8], a Kelvin model was used to model the high damping rubber bearing component and a constant Coulomb friction model was used to model the low friction sliding bearing, while the least squares method in the frequency domain was chosen as the identification procedure. In [9], the high damping rubber bearing component was modeled by a bilinear hysteretic model, the low friction sliding bearing component was modeled by Coulomb friction, while the least squares method was once more used as the dynamic identification technique. The next step was to introduce evolution strategies, where several of these were tested and the covariance matrix adaptation – evolution strategies turned out to be the most efficient strategy for the problem at hand, [10,11]. In [12], the covariance matrix adaptation – evolution strategies was used as the identification technique, a bilinear hysteretic model for the high damping rubber bearing component and a linear Coulomb friction model was used to replace the previously used constant Coulomb to model the low friction sliding bearing component. In [7], a new trilinear hysteretic model was introduced to simulate the behavior of the high damping rubber bearing component. A comparative study appearing in [13] involved a fractional derivative Zener model to describe the behavior of the high damping rubber bearing component and showed that the trilinear hysteretic model outperforms both bilinear hysteretic model and Zener models.