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Horizontal mechanical behavior of elastomeric bearings under eccentric vertical loading: Full-scale tests and analytical modeling

Zhu Hongping [a], Zhang Zixiang [a], Zhou Fangyuan [a,*], Luo Hui [a], Deng Xuan [b]

[a] School of Civil Engineering and Mechanics, Huazhong University of Science and Technology, Wuhan 430074, China
[b] China Institute of Building Standard Design and Research, Beijing 100000, China

HIGHLIGHTS

- The horizontal mechanical behavior of elastomeric bearings under eccentric vertical loading is investigated.
- Individual bearing tests are designed to account for the eccentric vertical loading cases.
- A modified Iizuka mechanical model is proposed to account for the behavior of the bearing under eccentric vertical loading.

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ABSTRACT

In general, elastomeric bearings are designed to sustain axial vertical loads, and the interaction between the vertical and horizontal mechanical behaviors of bearings have been researched in previous studies. However, elastomeric bearings are subjected to eccentric vertical loads in some engineering projects. For the purpose of investigating the influence of eccentricity in vertical loads on the horizontal mechanical behavior of elastomeric bearings, full-scale bearing tests were designed and conducted. The test results show that the hysteresis loops obtained in the eccentric loading tests are quite asymmetrical compared to those of the axial loading tests. The difference between the measured shear forces at two mirror symmetry points increases with increasing shear strain and vertical load. The skeleton curves of the hysteresis loops rotate about the point that mirrors the eccentric loading center. In addition, the horizontal stiffness of the skeleton curves obtained in the eccentric loading tests is smaller in the eccentricity direction compared to that of the axial loading tests. On the basis of the test observations, an analytical model is developed within the framework of the Koh-Kelly model to predict the horizontal mechanical behavior of elastomeric bearings under eccentric vertical loads. The analytical model simulates the test results well and can reproduce the rotation center of the skeleton curves observed in the eccentric loading tests.

1. Introduction

Elastomeric bearings have been widely accepted as an effective and economical seismic isolation device in the past two decades. A typical elastomeric bearing consists of alternating layers of rubber bonded to intermediate steel shim plates. The bonded rubber sheets can provide large horizontal deformation capacity and sustain large vertical loads. The introduction of elastomeric bearings at the base level can decouple a superstructure from high-frequency earthquake ground shaking and thus considerably reduce the inertial forces transmitted into the superstructure.

Because elastomeric bearings work under the combined action of horizontal and vertical loads, individual bearing tests were conducted to investigate the interaction between the horizontal and vertical mechanical properties of the bearings. The test results show that the horizontal stiffness decreases as the vertical load increases and that the bearing may buckle under large vertical loads, particularly when it moves into large shear strains [1–5].

To reproduce the test observations, several mechanical models have been proposed by former researchers [6–13]. Koh and Kelly [6,7] proposed a mechanical model that consists of a rotational spring to represent the flexural deformation and a shear spring to represent the shear deformation. This model is a simplification of the continuous beam model [6,14] derived from the work of Haringx [15] and can predict the decrease in horizontal stiffness with increasing vertical load. However, because the stiffness of the rotational spring and shear spring are both defined as constant, the original Koh-Kelly model cannot take into account the influence of shear strain on the horizontal mechanical behavior of the

* Corresponding author.
E-mail address: fangyuanzhou@hust.edu.cn (F. Zhou).

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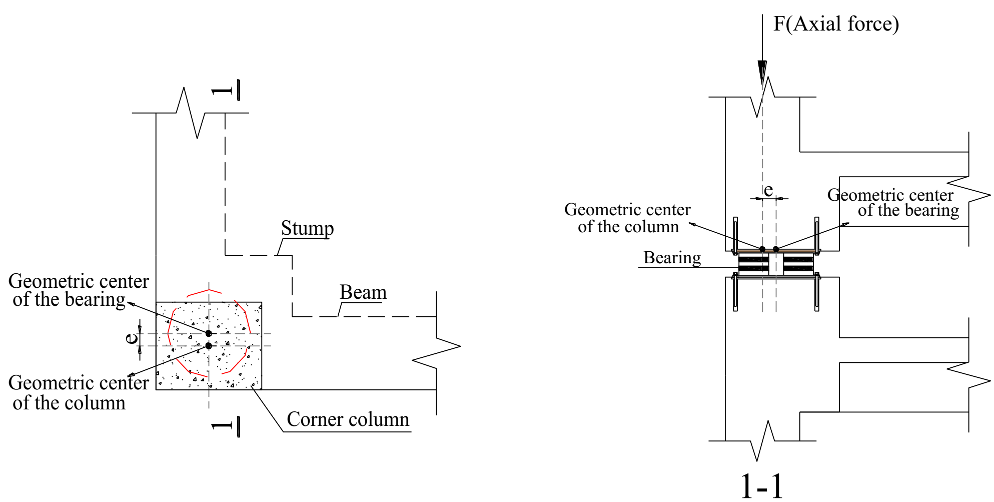
bearings, and the hardening effect for large shear strains was also neglected. To better predict the mechanical behavior of elastomeric bearings, Iizuka [8] expanded the Koh-Kelly model by introducing nonlinear constitutive relationships into the rotational and shear springs. The validity of this modified Koh-Kelly model was then confirmed by individual bearing tests. Ryan et al. [9] conducted an experimental study on the vertical load effects and proposed an analytical model for lead-rubber bearings by modifying the shear spring in the Koh-Kelly model with a bi-linear hysteretic relationship.

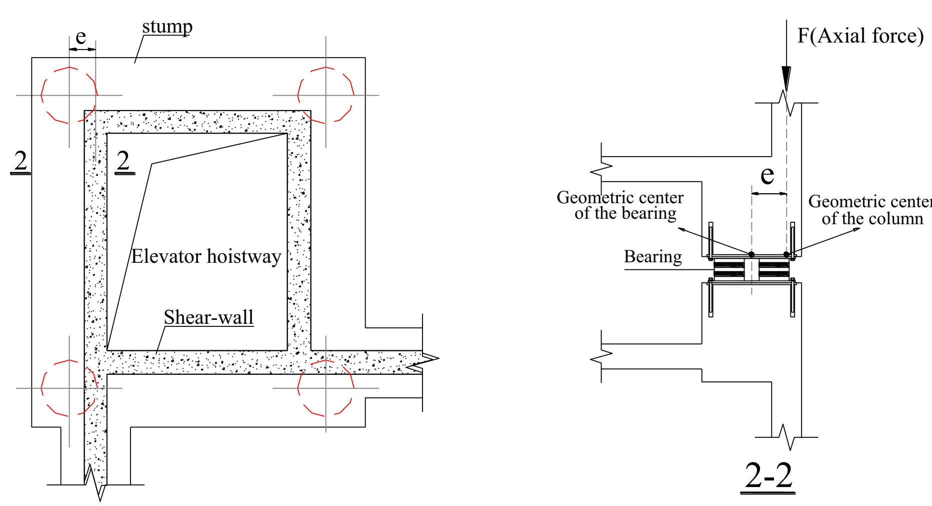
Yamamoto et al. [10] also proposed a more complex analytical model that is beyond the framework of the Koh-Kelly model. This model comprises shear and axial springs at the mid-height and two series of parallel vertical springs at the top and bottom boundaries. A previously developed nonlinear hysteretic model was introduced into the shear spring. The stiffness of the axial spring at mid-height was assumed to be temporarily infinite, and a nonlinear stress-strain relationship of rubber material was then introduced into the top and bottom spring groups to represent the vertical properties of the bearing. This model can predict the interaction between horizontal and axial mechanical properties and was then expanded into 3-D forms for both square and circular bearings [11,12]. Kumar M. et al. [13] presented a new mathematical model of natural rubber bearing and lead rubber bearing within the framework of a conventional two-node, 12 degrees-of-freedom, discrete element. Analytical expressions based on numerical simulation (Koh-Kelly model) and test observations (e.g., area-reduction method [3,16]) were adopted to consider the coupling of horizontal and vertical motion.

All of the aforementioned studies, including test investigations and analytical modeling, assumed that the bearing was subjected to axial vertical loads. However, in some engineering projects, the bearing is subjected to eccentric vertical loads in some situations, e.g., when the bearing is used to support side columns or the shear walls around an elevator hoistway (see Fig. 1(a-b)), and the effects of eccentric vertical loading on the horizontal mechanical behavior of elastomeric bearings has not been studied to date.

To gain insight into the effects of eccentric vertical loads, full-scale bearing tests were designed and conducted under axial and eccentric vertical loads, respectively. The results show that eccentricity in vertical loads considerably influences the horizontal mechanical behavior of the elastomeric bearings. The skeleton curves of the hysteresis loops under different eccentric vertical loads exhibit asymmetry phenomena and rotate about the point that mirrors the eccentric loading center with variation in the vertical load.



(a) Bearing that supports a corner column



(b) Bearing that supports shear walls around an elevator hoistway

Fig. 1. Bearings subjected to eccentric vertical loads.