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Significance of stiffening of high damping rubber bearings on the response of base-isolated buildings under near-fault earthquakes

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ABSTRACT

High Damping Rubber Bearings (HDRBs) are among various types of laterally flexible isolation system elements that effectively protect structures from detrimental effects of earthquakes by lengthening their fundamental periods. However, large isolator displacements resulting in strains larger than 100% may come into scene in case of near-fault ground motions containing long-period and large-amplitude velocity and/or displacement pulses. This is particularly important when HDRBs are used since the post-yield stiffness of an HDRB increases due to inherent strain hardening characteristics when a threshold isolator displacement limit is exceeded. Therefore, it may be critical to consider the stiffening of HDRBs in modeling of these elements for accurate seismic response evaluation of the buildings equipped with HDRBs that are located in near-fault regions. In this study, the significance of stiffening of HDRBs on the response of base-isolated buildings is investigated by conducting nonlinear time history analyses of benchmark six-story base-isolated buildings which employ HDRBs that are represented by non-stiffening or stiffening models under both historical and synthetic near-fault ground motions of various magnitudes and fault distances. The structural response parameters included in the comparisons are base displacements, story drifts, and floor accelerations. It is found that, the significance of stiffening of HDRBs on the response of base-isolated buildings under near-fault earthquakes becomes more prominent as the earthquake magnitude increases and the fault distance decreases and thus suggestions for modifications to seismic code regulations are made accordingly.

1. Introduction

In addition to low-damping natural rubber bearings (LDRBs) and lead-rubber bearings (LRBs), high damping rubber bearings (HDRBs) are among the rubber-based bearing types which are commonly preferred in base-isolation applications [1]. HDRBs have complex structures since they are formed by adding extra fine carbon blocks, oils, resins, and other fillers to the natural rubber in order to increase their damping property [2,3] which in turn cause HDRBs to exhibit nonlinear hysteretic material behavior under earthquake loadings and thus it may not be easy to capture their actual behavior [4].

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The force-displacement relationships of the HDRBs may be represented at least with two linear branches whose slopes are referred as the pre-yield stiffness and the post-yield stiffness since the shear stiffness of HDRBs is high for low strains and decreases as the strain increases. This bi-linear modeling, which makes it relatively simpler to characterize the mechanical properties of rubber based bearings (e.g. HDRBs, LRBs), is commonly preferred (e.g. in studies [5–8]) over many other models that are proposed for modeling the force-deformation relationships of HDRBs [2].

The force-displacement relationships of HDRBs may be properly represented with the bi-linear model in a range of low-to-moderate shear strains. However, large earthquakes may cause strains larger than 100%. In such cases, the stiffness of HDRBs increases and thus it may be critical to use advanced analytical models which take this stiffening characteristic into account, rather than simpler bi-linear models, for accurate representation of the behavior of HDRBs and consequently for accurate seismic response evaluation of the structures equipped with such isolation systems that are located especially in near-fault regions.

In this study, mathematical models of two benchmark six-story buildings are developed in order to numerically investigate the significance of stiffening of HDRBs on the response of base-isolated buildings under near-fault earthquakes. The isolation system of one of the buildings is modeled by taking the stiffening characteristics of the bearings into account whereas that of the other one is modeled by neglecting this characteristic of HDRBs. As this study particularly concentrates on the sensitivity of the significance of the use of stiffening HDRB models to the earthquake magnitude and the nearest fault distance, nonlinear time history analyses of the benchmark buildings with stiffening and nonstiffening HDRBs are conducted under synthetic pulse-like near-fault ground motions for various moment magnitudes and nearest fault distance values as well as historical near-fault earthquakes. For the assessment of the significance of stiffening of HDRBs on the response of base-isolated buildings, base displacements, story drifts, and floor accelerations are considered as the structural response parameters.

In the literature, there exist various models developed to characterize the force-deformation relationships of inelastic structural elements such as HDRBs. The models described by algebraic equations, such as Ramberg-Osgood model [9], bi-linear and elastoplastic models, and the models described by differential equations, such as Wen's model [10], are the two explicit and the earliest types of models, developed for inelastic structural elements [11]. And of the advanced analytical models specifically developed for accurate representation of the force-deformation relationships of HDRBs in the literature [12–18], the model developed by Tsopelas et al. [12] is used in this study, since this model has been implemented in 3D-BASIS-ME [12], which is an academic software used world-wide in research studies for the nonlinear dynamic analysis of three dimensional base-isolated structures.

Among the various analytical pulse models that can effectively represent pulse-like near-fault ground motion records available in the literature [19–26], the models proposed by [23,25], and [26] are represented by single functions and have been verified using a large number of recorded ground motions [27]. Furthermore, it is verified by [28–30] that Agrawal and He [23] pulse model could be used in lieu of the real ground motion records in the research studies conducted for the investigation of dynamic response of base-isolated structures. Therefore, it is determined to use the Agrawal and He [23] pulse model, in this study.

The assumptions of this study include the following: (1) soil-structure interaction is not taken into account; (2) superstructure is assumed to remain linear-elastic throughout the time-history analyses; and (3) the superstructure and the seismic isolation system is assumed to be fully symmetric. The organization of the text is as follows: First, the modeling details of the structural model consisting of the superstructure and the seismic isolation system is described. Secondly, information on the historical earthquakes that are representatives of near-fault ground motions and the methodology for developing synthetic near-fault ground motions of various magnitudes at selected fault distances are given. Then, the results of nonlinear time history analyses under aforementioned ground motion records are presented for stiffening and

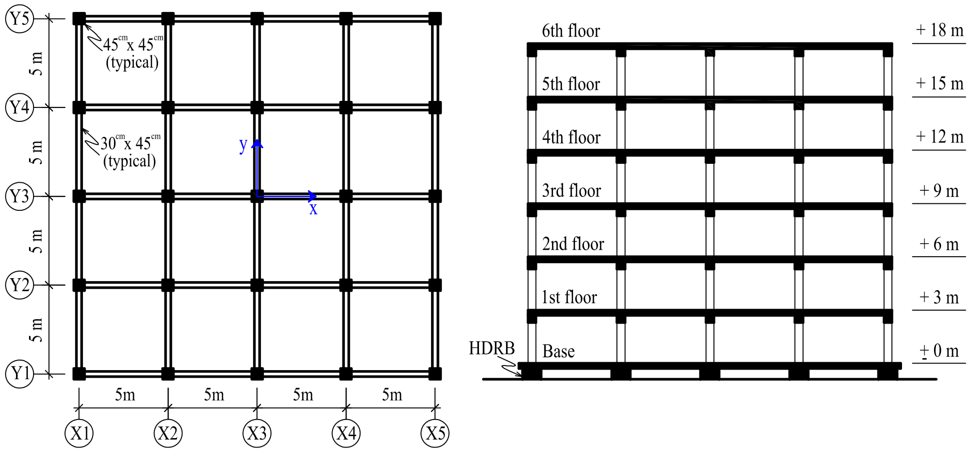

Fig. 1. Typical floor plans and elevation views of the base-isolated buildings.