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Effect of LRB isolators and supplemental viscous dampers on seismic isolated buildings under near-fault excitations

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Abstract

Base isolation is a quite sensible structural control strategic design in reducing the response of a structural system induced by strong ground motions. It is clear that the effects of near-fault (NF) ground motions with large velocity pulses can bring the seismic isolation devices to critical working conditions. In the present paper, nonlinear time history analyses were performed using a commercial structural analysis software package to study the influence of isolation damping on base and superstructure drift. Various lead-rubber bearing (LRB) isolation systems are systematically compared and discussed for aseismic performances of two actual reinforced concrete (RC) buildings. Parametric analysis of the buildings fitted with isolation devices is carried out to choose the appropriate design parameters. The efficiency of providing supplemental viscous damping for reducing the isolator displacements while keeping the substructure forces in reasonable ranges is also investigated.
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Keywords: Base isolation; LRB; Viscous damping; Near-fault; Strong ground motion; FEM

1. Introduction

Buildings are vulnerable when subjected to severe earthquakes. Although considerable progress was made in earthquake engineering towards the end of the century, catastrophic building failure examples are found wherever strong ground motion earthquakes attack. Structural members and their internal contents can be protected against severe earthquake events with the installation of structural isolation devices to add damping to the isolated structure. The concept of the base isolation technique is to separate the structure from the ground in order to avoid earthquake damage [1]. However, we can modify the demand it makes on the structure by preventing the motions being transmitted from the foundation into the structure above. During this procedure a significant amount of energy is dissipated while an appropriate stiffness of the isolated system is provided to maintain structural integrity.

A significant amount of both past and recent research in the area of base isolation has focused on the use of elastomeric bearings, such as high-damping rubber bearings (HDRB) and lead-rubber (LRB) bearings [2–5]. Such devices have already been used over many years by engineers and require only minimal initial cost and maintenance compared to other passive, semi-active and active response modification and energy absorption devices [6].

In the case of far-field (FF) ground motions the isolators experience acceptable deformations. However, for structures subjected to near-field (NF) ground motions, the isolator displacements tend to be considerable [7,8]. Therefore, isolators with very large dimensions may be required for structures located in NF areas. These costly geometries are in contradiction with the main objective of implementing seismic isolators to reach a more economical and practical solution by mitigating the strong ground motion pulses transferred to the building. But, since those pulses can reach some peak velocities of the order of 0.5 m/s and durations of 1–3 s, it is obvious that it leads to considerable interest to researchers, and recently several papers for investigating the dynamic behavior of base-isolated buildings under NF motion were published. It was observed that LRB-isolated buildings with selected properties might perform poorly and can cause instability in the isolation system. Since the LRB system is a very common

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isolation system equipped with all the desirable features of base isolation, it is necessary to investigate those parameters that affect the dynamic behavior of an isolated system.

To address the problem stated above, the efficiency of providing different LRB systems for actual RC buildings, in combination with supplemental dampers for reducing the isolator displacements while keeping the inter-story forces in reasonable ranges, was investigated by many researchers [9–11]. The response of this combined isolation action as well as the superstructure behavior seems to be effective for NF ground motions. However, such a complex isolation system leads to undesirable results under moderate or strong FF earthquake excitations. It is obvious that a significant increase in stiffness, although controlling displacement, activates higher modes of the dynamic model, also taking into account that supplemental viscous dampers, although helping in this control, on the contrary introduce secondary damping forces with complex coupling effects. Therefore, there is a need to study extensively the aseismic performance of different LRB isolators with or without the combination of supplemental viscous dampers for structures experiencing NF motions. This study of the aseismic performance of different LRBs under the effect of supplemental viscous damping is the main objective of this paper. Thus, parametric analysis for variations in the fundamental isolation period and damping is performed. The recommended ranges of the design parameters are also presented in this study. The peak responses of the isolated structure are obtained and the relative effectiveness of the various isolation systems is evaluated for the selected design parameter of isolation systems.

2. Modeling of isolation system

2.1. LRB isolators

As stated previously, the main objective of the present research is to study the effect of LRBs and supplemental viscous dampers on the seismic performance of isolated buildings in relation to the characteristics of the NF ground motion and isolator properties. Seismic isolators are generally classified into two general groups as rubber-based (such as high-damping rubber and lead-rubber bearings [12]) and sliding-based (such as Eradiquake [13] and friction pendulum bearings [12]). The rubber-based bearing isolation system consists of layers of rubber and steel, with the rubber being vulcanized to the steel plates for horizontal flexibility and vertical stiffness. In this paper the case of the lead-rubber bearing (LRB) isolator will be presented. This isolator consists of a lead-plug insert which provides its characteristic hysteretic energy-dissipation effect. Therefore, the LRB system is able to support the structure vertically, to provide the horizontal flexibility together with the restoring force, and to provide the required hysteretic damping.

In the present paper, the isolators were initially designed to follow some available recommendations of the Uniform Building Code (UBC-97) [14]. The mechanical properties of the LRB isolation system were set to comply with a recommendation of the UBC-97 building code. The design

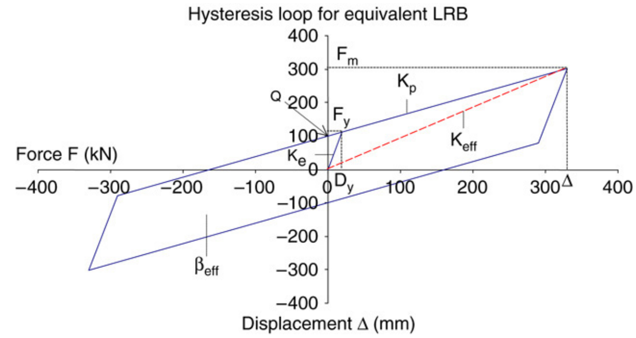

Fig. 1. Typical bilinear LRB hysteresis.

parameters considered here are: the ratio Q/W of the characteristic strength Q over the total weight on the isolation system W, the yield force F_y, the isolator diameter D, the lead core diameter d, the number of rubber layers n, and the layer thickness t. For design and analysis, the shape of the nonlinear force–deflection relationship, termed the hysteresis loop (represented as a bilinear curve as shown in Fig. 1), has an elastic (or unloading) stiffness k_e and a yielded (or post-elastic) stiffness k_p.

The elastic stiffness k_e is defined as the ratio of the yield strength to the yield displacement, as expressed in equation $k_e = \frac{F_y}{D_y}$, while the post-yield stiffness k_p is given by the formula

$$k_p = \frac{G \cdot A_r}{t_r} f_L, \tag{1}$$

where G is the shear modulus of the rubber, A_r is the cross-sectional area of the rubber layers, t_r is the total thickness of rubber consisting of n layers, and the factor f_L is equal to 1.5. The characteristic strength Q (force intercept at zero displacement) is given by the equation

$$Q = A_{\text{pb}} \sigma_{\text{ypb}}, \tag{2}$$

where A_{pb} is the area of lead core, and σ_{ypb} the yield strength of the lead core (ranging between 7 and 8.5 MPa). The average or effective stiffness k_{eff} is defined as the ratio between the force F_m, occurring at a specified LRB isolator displacement Δ, and the displacement Δ:

$$k_{\text{eff}} = \frac{F_m}{\Delta}. \tag{3}$$

The effective stiffness k_{eff} can also be expressed as a function of the characteristic strength Q as in the following equation:

$$k_{\text{eff}} = k_p + \frac{Q}{\Delta} \quad (\text{when } \Delta > D_y) \tag{4}$$

where D_y is the yield displacement as shown in Fig. 1. On the other hand, when the design displacement $\Delta < D_y$, the effective stiffness $k_{\text{eff}} = k_e$. The force F_m can be defined as

$$F_m = Q + k_p \Delta \tag{5}$$

while the yield force F_y can be obtained from

$$F_y = Q + k_p D_y. \tag{6}$$

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