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Optimum characteristic properties of isolators with bilinear force–displacement hysteresis for seismic protection of bridges built on various site soils

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ABSTRACT

In this study, closed form equations as functions of the isolator, bridge and ground motion properties are formulated to calculate the optimum characteristic strength, Q_d and post-elastic stiffness, k_d, of the isolator to minimize the maximum isolator displacement (MID) and force (MIF) for seismic isolated bridges (SIBs). For this purpose, first, sensitivity analyses are conducted to identify the bridge, isolator and ground motion parameters that affect the optimum values of Q_d and k_d. Next, for the identified parameters, nonlinear time history analyses of typical SIBs are conducted to determine the optimum values of Q_d and k_d for a wide range of values of the parameters. Next, nonlinear regression analyses of the available data are conducted to obtain closed form equations for the optimum values of Q_d and k_d, to minimize the MID and MIF. The equations are then simplified for various site soil conditions. It is observed that the optimum Q_d and k_d are highly dependent on the site soil condition. Furthermore, the optimum Q_d is found to be a linear function of the peak ground acceleration.

1. Introduction

Seismic isolation of bridges is a design methodology that is based on limiting the magnitude of the seismic forces transferred to the substructures through yielding of the isolators placed between the superstructure and the substructures. The performance of seismic isolated bridges (SIBs) is measured by the maximum isolator force and displacement (MIF and MID). The MIF represents the magnitude of the seismic force transferred to the substructures. Thus, it has a remarkable effect on the design of the substructures. The MID is generally used to determine the isolator size as well as the width and type of the expansion joints. In some cases, the widths of the substructures may be governed by the MID. Accordingly, for a given ground motion, smaller isolator force and displacement will produce a more economical bridge design under seismic effects.

Seismic isolators used in bridge applications may be classified into two general groups as rubber-based and sliding-based. Some examples of rubber-based isolators are high damping rubber and lead-rubber bearings [1]. Some examples of friction-based isolators are Eradiquake and friction pendulum bearings [2]. The force–displacement hysteresis of these isolators is generally idealized as bilinear for design purposes [2]. A typical bilinear force–displacement hysteresis of an isolator and a typical isolated bridge substructure are shown in Fig. 1(a) and (b). In the figures, Q_d is the characteristic strength, k_u is the elastic stiffness, k_d is the post-elastic stiffness, F_y and u_y are, respectively, the yield force and displacement and F_i and u_i are, respectively, the maximum (or design) force and displacement of the isolator. The characteristic strength, Q_d and the post-elastic stiffness, k_d, are the main isolator parameters that affect the behavior of a SIB for a given ground motion with specific frequency characteristics and intensity [3]. Thus, the optimal selection of these isolator parameters based on minimizing the MID and MIF will result in an economical design of the SIB.

Several research studies have been conducted to identify the optimal characteristic properties of isolators or yielding systems for the seismic design of structures. In the early sixties, Veletsos et al. [4] developed the concept of constant ductility spectra to determine the lateral strength required to limit the maximum inelastic deformation in a structure to a prescribed value for the conditions considered. Constantinou and Tadjbakhsh [5] studied the optimal design of a hybrid base isolation system consisting of rubber and friction bearings. It was concluded that a small amount of friction increases the effectiveness of the system compared with the same system but without frictional elements. Park and Otsuka [6] developed a simple linear equation for SIBs to obtain the optimal characteristic strength, Q_d, of the isolator to maximize the ratio of the energy absorbed by the isolator to the earthquake input energy. However, the equation is developed using a single ground motion and is only a function of the ground motion intensity. Therefore, the equation may not properly reflect the effect of the properties of the bridge and the isolator on

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