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Influence of soil conditions on the optimal sliding friction coefficient for isolated bridges

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ABSTRACT

The aim of this work is to evaluate the optimal properties of friction pendulum system (FPS) bearings for the seismic protection of bridge piers under earthquake excitations having different frequency characteristics representative of different soil conditions in order to reduce the seismic vulnerability of infrastructures increasing their safety level. A two-degree-of-freedom model is adopted to describe, respectively, the response of the infinitely rigid deck isolated by the FPS devices and the elastic behaviour of the pier. The FPS isolator behaviour is modeled through a widespread velocity-dependent rule. By means of a non-dimensional formulation of the motion equations, proposed in this study, a wide parametric analysis considering several structural parameters is performed to investigate their influence on the response parameters relevant to the performance assessment. Seismic excitations, modeled as time-modulated filtered Gaussian white noise random processes having different intensities and frequency contents, are considered. Specifically, the filter parameters, which control the frequency contents, are properly calibrated to reproduce stiff, medium and soft soil conditions, respectively. Finally, multi-variate non-linear regression relationships are derived to estimate the optimum values of the sliding friction coefficient able to minimize a percentile of the pier displacements relative to the ground as a function of the structural properties, of the seismic input intensity and of the soil condition.

1. Introduction

Seismic isolation of bridges makes it possible to uncouple the deck from the horizontal components of the earthquake motion, leading to a substantial reduction of the deck acceleration and, consequently, of the forces transmitted to the pier. Indeed, Tsopelas et al. [1], Jangid [2], Ghobarah and Ali [3] developed experimental and analytical studies of a seismically isolated and a comparable non-isolated bridge demonstrating a substantial reduction of the seismic forces to the substructure in comparison to the response of the non-isolated bridge. Tongaonkar and Jangid [4] evaluated the performance of three-span continuous deck bridges using linear and non-linear model for the elastomeric bearings to show that these devices are quite effective in reducing the seismic response of the bridges.

In the last years, friction pendulum system (FPS) devices have often been preferred to other isolators for their capability of providing an isolation period independent of the mass of the supported structure, their capacity to assure high dissipation and recentering, and their longevity and durability properties [5,6]. Several experimental and numerical researches have been developed to examine the behaviour of these isolators by means of dependable models [7–12]. In [13], with reference to an equivalent two-degree-of-freedom (2dof) model for base-isolated building frames, a non-dimensionalization of the motion equation considering different isolator and system properties has been proposed. Contextually, other studies have been focused on the seismic response of bridge isolated with FPS isolators. In particular, Kim and Yun [14] studied the positive effects of a double concave friction pendulum system on a bridge response. Murat and DesRoches [15] analyzed the effect of modeling parameters on the response of a three-dimensional multi-span continuous steel girder bridge model seismically isolated by the FPS. Moreover, other works have been more oriented to develop design approaches for the isolators and to identify the optimal isolator properties. In this context, the seismic reliability-based design (SRBD) approach has been proposed and widely discussed in [16–20] as a new methodology useful to provide design solutions for seismic devices taking into account the main uncertainties relevant to the problem. Jangid [21], assuming a stochastic model of the earthquake ground motion, considered the seismic performance of a bridge

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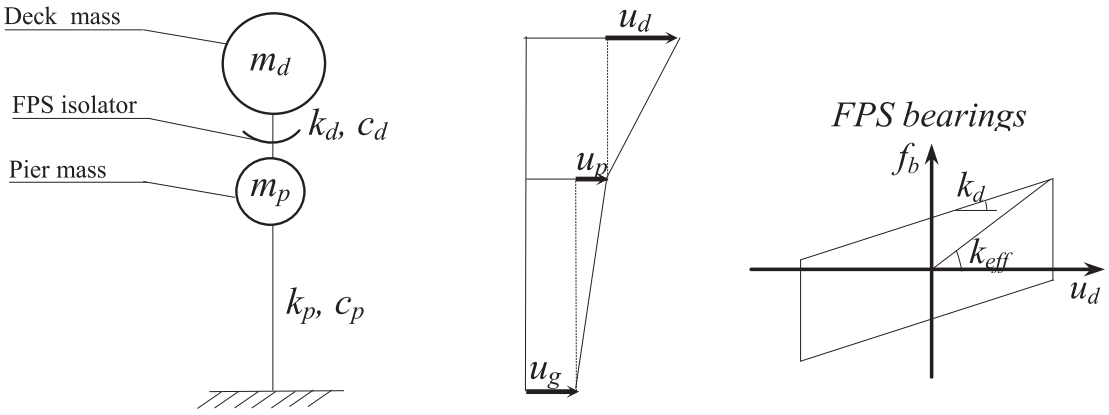

Fig. 1. 2dof model of a bridge isolated by FPS bearings.

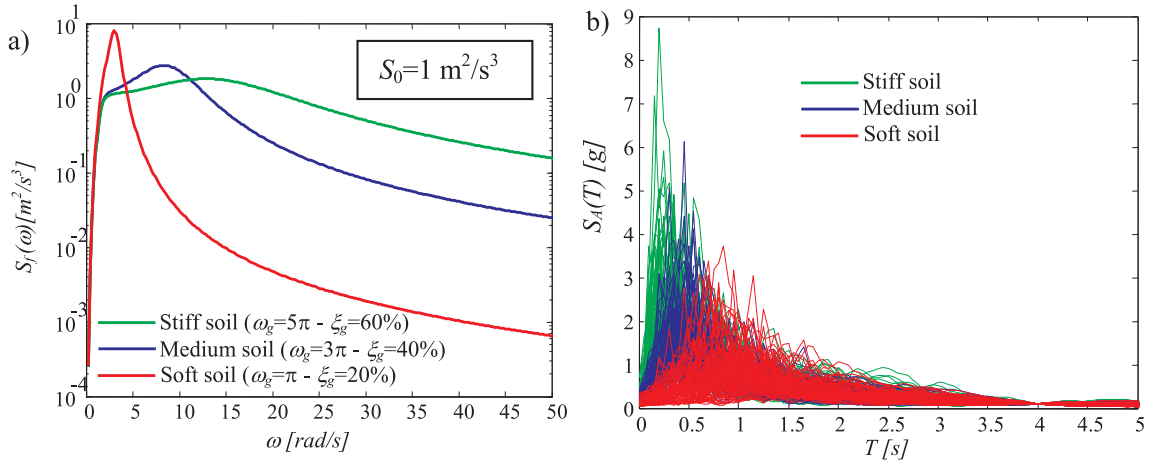

Fig. 2. PSD functions corresponding to stiff, medium and soft soil conditions (a); Pseudo-acceleration response spectra for the 300 records scaled to the common seismic intensity measure $S_A(T)$ = 0.1g, for T = 4s (b) (modified from [23]).

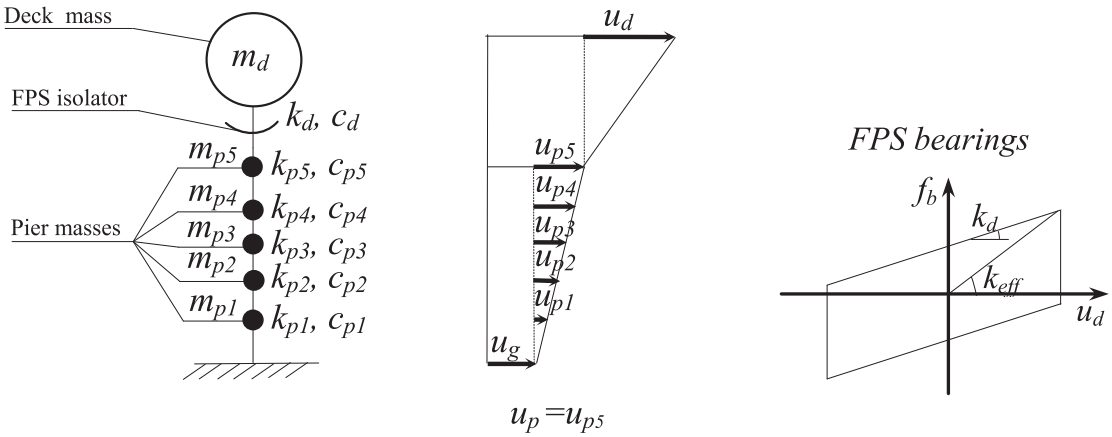

Fig. 3. 6dof model of a bridge isolated by FPS bearings.

equipped with FPS devices, characterized by a Coulomb behaviour, illustrating that there exists an optimal value of the friction coefficient for which the pier base shear and deck acceleration can be minimized. These values depend on the bridge properties and they increase with decreasing values of the isolation period. In [22], the seismic performance of bridges isolated with FPS considering a specific site and different limit states has been investigated.

The influence of soil characteristics in terms of frequency content on the seismic performance of elastic building frames isolated with FPS isolators has been investigated in [23] by also proposing regression expressions useful to estimate the optimal isolator friction properties. Equally, Kulkarni and Jangid [24], considering non-stationary random processes, compared the stochastic response of a base-isolated structure with superstructure modeled as flexible and rigid leading to the conclusion that the seismic isolation is more efficient for firm or rock soils than the soft soils. Other works (e.g., [25–28]) concerning isolated