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The effect of spatially varying earthquake ground motions on the stochastic response of bridges isolated with friction pendulum systems

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Abstract

In this paper, a comprehensive investigation of the effect of spatially varying earthquake ground motions on the stochastic response of bridges isolated with friction pendulum systems is performed. The spatially varying earthquake ground motions are considered with incoherence, wave-passage and site-response effects. The importance of the site-response effect, which arises from the difference in the local soil conditions at different support points of the isolated bridge, is investigated particularly. Mean of maximum and variance response values obtained from the spatially varying earthquake ground motions are compared with those of the specialised cases of the ground motion model. It is shown that site-response component of the spatially varying earthquake ground motion model has important effects on the stochastic response of the isolated bridges. Therefore, to be more realistic in calculating the isolated bridge responses, the spatially varying earthquake ground motions should be incorporated in the analysis.

Keywords: Spatially varying earthquake ground motion; Site-response effect; Incoherence effect; Uniform ground motion; Isolated bridge; Friction pendulum system

1. Introduction

Friction pendulum systems are sliding bearings that make use of a spherical concave surface to provide a restoring force and friction force to dissipate earthquakes energy [1]. The systems have been employed for seismic protection of bridges [2–4]. The failure of bridges during earthquakes causes serious consequences. The seismic forces on such structures can be reduced by means of fundamental period of bridges is lengthened and/or the energy dissipating capacity of bridges is increased. Using the equivalent linearization technique, Li [5] studied the response of a typical three-span bridge structure with a seismic isolation system consisting of rubber bearings and hysteretic dissipaters in longitudinal direction. It is concluded that hysteretic damper act most effectively when mounted on a stiff supporting structure, their effectiveness decreases with increasing flexibility of the supporting structure. Besides, it is reported that when the larger value of maximum allowed isolator displacements is used, the isolation system is more effective. Pagnini and Solari [6] carried out the stochastic response of a typical three-span bridge isolated with rubber bearings and hysteretic dissipaters using the stochastic equivalent linearization technique. In these studies, earthquake ground motions were used as uniform ground motions. In fact, earthquake ground motions are not the same at support point of long span structures like pipelines, bridges, and dams. This is because of complex nature of the earth crust. In recent years, the earthquake response analyses of long span structures subjected to spatially varying earthquake ground motions have been special interest [7,8]. Harichandran et al.

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[9] performed stochastic response analysis of suspension and deck arch bridges to spatially varying earthquake ground motions. They underlined the importance of the effect of spatially varying earthquake ground motions on the response of long span structures. Zerva [10] evaluated the responses of continuous two- and three-span beams to spatially varying ground motions and examined the validity of the commonly used assumption of equal support motion. Zembaty and Rutenberg [11] presented a numerical sensitivity study of the local site effects on a four-span bridge response. An analysis of a bridge response with supports founded on different soils was carried out. Allam and Datta [12] presented a frequency domain spectral analysis for the seismic analysis of cable-stayed bridges for the multi-component stationary random ground motion. The ground motion was represented by its power spectral density function and a spatial correlation function. It is concluded that the dynamic responses of the non-isolated bridge for the soft soil condition could be significantly higher than those for the firm soil condition. Soyluk [13] investigated the spatial variability effects of ground motions on the dynamic behaviour of long span bridges by a random vibration based spectral analysis approach and two response spectrum methods. Soyluk and Dumanoglu [14] investigated the stochastic response of a cable-stayed bridge subjected to spatially varying ground motions based on a recently developed model. It is observed that the responses are generally the smallest for uniform ground motion; the responses obtained from spatially varying earthquake ground motions are generally the largest. It is also stated that spatially variability and propagation effects of ground motions have important effects on the dynamic behaviour of the non-isolated bridge and the variability of ground motions should be included in the stochastic analysis of non-isolated cable-stayed bridges.

It will be seen from the literature review above that the importance of spatially varying earthquake ground motions on the non-isolated bridge was investigated by many researches. As a result of these studies, it is highlighted that spatially varying earthquake ground motions including incoherence, wave passage and site-response effects should be taken into account separately and altogether in the analyses. The effects of spatially varying earthquake ground motions on the isolated bridges are not comprehensively investigated. For this reasons, the focus of this study is to investigate the effect of the spatially varying earthquake ground motion on the stochastic response of isolated multi-span continuous bridges with friction pendulum system.

2. Friction pendulum system

Friction pendulum system (FPS) proposed by Zayas et al. [1] is an innovative seismic isolation system which appears to offer improvements in strength, longevity, versatility, ease of installation. The principles of the FPS coincide with

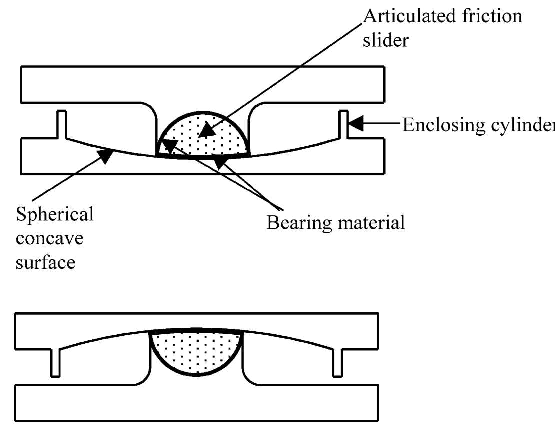

Fig. 1. The cross-section of the friction pendulum system.

the simple pendulum's. The supported structure by FPS responds to earthquake ground motion with small amplitude pendulum motions and its friction damping absorbs the earthquakes energy. The operation of the connection is the same whether the spherical concave surface is facing up or down, Fig. 1.

The isolators used as FPS is shifting the natural period of the supported structure. The natural period of vibration is given by following equation [1]

$$T = 2\pi\sqrt{\frac{R}{g}} \quad (1)$$

where R is the radius of spherical concave surface, and g is the acceleration of gravity. Eq. (1) shows that the natural period of vibration is independent of mass, but it is controlled by the selection of the radius of spherical concave surface. The force–displacement relationship of the FPS in any direction may be given by the expression [15]

$$F = \frac{W}{R} v_b + \mu_s W \,\mathrm{sgn}(\dot{v}_b) \quad (2)$$

where W, R, v_b μ_s and $\dot{v}_b$ are the total weight carried by the FPS, the radius of spherical concave surface, the sliding displacement, the coefficient of friction on the sliding surface and the sliding velocity, respectively; sgn () is the signum function. In Eq. (2), the first is the pendulum component and the second is the friction component. The lateral restoring stiffness of the FPS is given by following equation [1].

$$k_b = \frac{W}{R} \quad (3)$$

It is also shown in Eq. (3) that the stiffness of the pendulum depends on weight carried by bearing. The coefficient of the sliding friction of Teflon–steel interfaces depends on velocity of sliding and bearing pressure. The coefficient of the sliding friction is given