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Multiple-support seismic response of Bosporus Suspension Bridge for various random vibration methods

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ABSTRACT

This paper presents a study about the spatial variability effects of ground motions on the dynamic behavior of a suspension bridge by a random vibration based spectral analysis approach and two response spectrum methods. Bosphorus Suspension Bridge built in Turkey and connects Europe to Asia in Istanbul is selected as a numerical example. The spatial variability of ground motions between the support points is taken into account with a coherency function that characterizes the incoherence, wave-passage and site-response effects. Power spectral density function and response spectrum values used in random vibration analyses are determined depending on the recordings of August 17, 1999, Kocaeli, Turkey earthquake. From the results, it can be observed that the structural responses for each random vibration analysis depend largely on the intensity and frequency contents of power spectral density functions.

1. Introduction

Since an earthquake excitation consists of the superposition of a large number of waves with different characteristics, seismic ground motions at the supports can vary significantly along a suspension bridge span. The variations in the support motions can significantly influence the internal forces generated in the structure. So, in calculating the seismic response of suspension bridges, the assumption of uniform ground motion at the supports of this extended structures cannot be considered valid.

In previous studies, analyses of bridges to multiple-support or spatially varying seismic ground motions were performed by various researchers [1–9]. All these studies underline the requirement of the consideration of multiple-support or spatially varying seismic excitations for the dynamic response analysis of suspension bridges. The effect of spatially varying ground motions on the random vibration response of bridges has been studied usually by spectral analysis approach [9–17] and sometimes by response spectrum analysis [8,18,19] in the literature. Comparison of spectral analysis approach and response spectrum analysis of long-span bridges to spatially varying ground motions is meager. Recently, the spatial variability effects of ground motions on the dynamic behavior of deck-type arch and cable-stayed bridges by different random vibration

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methods were investigated by Soyluk and Sıcacık [20]. As known, while suspension bridges cover the center span range of 500–3000 m, cable-stayed bridges cover the center span range of 200–1000 m and steel arch bridges cover the span range of 60–600 m. Random vibration responses of these bridges are different from each other. Although the effect of spatially varying ground motions on the random vibration response of suspension bridges have been investigated either by spectral analysis approach or by response spectrum method, it has not been found any publication in the literature that includes the random vibration based both spectral and response spectrum analyses of suspension bridges subjected to spatially varying ground motions including the incoherence, wave-passage and site-response effects.

The objective of this study is to compare the random vibration response of a suspension bridge to spatially varying ground motions considering the coherency function that characterizes the three spatial variability effects namely the incoherence, wave-passage and site-response. Three different random vibration methods are utilized to determine the dynamic behaviors of the considered suspension bridge, Bosporus Bridge, in this study. As one of these methods is the spectral analysis approach, the other two methods are the response spectrum methods.

2. Formulation

2.1. Spectral analysis approach

Spectral analysis approach is based on the principles of stationary random vibration theory and provides an approximate estimate of the mean of the absolute maximum response of the structure. Any response quantity can be decomposed into dynamic and pseudo-static components, when there is a differential excitation at the supports. The total mean-square response can be obtained from Harichandran and Wang [21]

$$\sigma_z^2 = \sigma_{z_d}^2 + \sigma_{z_s}^2 + 2Cov(z_s, z_d) \tag{1}$$

where $\sigma_{z_s}^2$ and $\sigma_{z_d}^2$ are the pseudo-static and dynamic variances, respectively, and $Cov(z_s, z_d)$ is the covariance between the pseudo-static and dynamic responses. The three components on the right-hand side of Eq. (1) are given by

$$\sigma_{z_s}^2 = \sum_{k=1}^{r}\sum_{l=1}^{r} A_k A_l \int_{-\infty}^{\infty} \frac{1}{\omega^4} G_{\ddot{u}_k \ddot{u}_l}(\omega) d\omega \tag{2}$$

$$\sigma_{z_d}^2 = \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{r}\sum_{l=1}^{r} \psi_i \psi_j \Gamma_{ki} \Gamma_{lj} \int_{-\infty}^{\infty} H_i(-\omega) H_j(\omega) G_{\ddot{u}_k \ddot{u}_l}(\omega) d\omega \tag{3}$$

$$Cov(z_s, z_d) = \sum_{j=1}^{n}\sum_{k=1}^{r}\sum_{l=1}^{r} \psi_j A_k \Gamma_{lj} \left(-\int_{-\infty}^{\infty} \frac{1}{\omega^2} H_j(\omega) G_{\ddot{u}_k \ddot{u}_l}(\omega) d\omega \right) \tag{4}$$

in which n is the number of modes used in the analysis, r is the number of restrained degrees of freedom, ψ_j is the response z from the jth mode, A_k is the response z due to a unit displacement of support degree of freedom k, Γ_{ki} is the participation factor corresponding to mode i and support degree of freedom k, $H_j(\omega)$ is the modal frequency response function and $G_{\ddot{u}_k \ddot{u}_l}(\omega)$ is the cross spectral density function of accelerations between support degree of freedom k and l.

In the random vibration analysis the mean of the absolute maximum value (μ) can be written as

$$\mu = p\sigma_z \tag{5}$$

where p is a peak factor and σ_z is the standard deviation of the total response [22].

2.2. Response spectrum method

The multiple support response spectrum method based on fundamental principles of stationary random vibration theory was developed by Der Kiureghian and Neuenhofer [22]. This rule provides the response of a linear system subjected to incoherent support excitations directly in terms of the conventional response spectra at the support degrees of freedom and a coherency function describing the spatial variability of the ground motion. The combination rule for the mean of absolute peak response is given in the form [22]

$$E\left[\max|z(t)|\right] = \left[\sum_{k=1}^{m}\sum_{l=1}^{m} a_k a_l \rho_{u_k u_l} u_{k,\max} u_{l,\max}\right.$$