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Stochastic dynamic response of short-span highway bridges to spatial variation of blasting ground vibration

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ABSTRACT

This study carries out a parametrical stochastic analysis of a short-span highway bridge to spatially varying blast ground motion and exhibits wave passage, loss of coherency and attenuation effects of spatial variation of blast ground motion at the rock medium. Wave passage time delay effect is due to differences in arrival times of shock waves at different locations and loss of coherence of shock waves is due to multiple reflections refraction as they propagate through the highly inhomogeneous rock medium. The fully coherent model is considered to take into account the loss of coherency of blast ground motion. Furthermore, before the power spectral density and cross spectral density functions of shock time histories are produced, the attenuation of shock waves are taken into account in this study. A short-span highway bridge is considered in order to be analyzed for spatially varying blast ground motion. Different charge weights and distances from the charge center are considered to investigate the effects of blast ground motion on the bridge. The comparisons of results of the shaded image counters and one standard deviation as well as power spectral densities of the response of the highway bridge according to the three different charge weights with the three different charge centers are investigated for numerical calculations. The results of the analyses revealed that spatial variation of blast ground motion significantly affects stochastic responses of short-span highway bridges.

1. Introduction

One of the most important potential environmental threats on structures as external loads like earthquake and wind is surface explosions. This threat may cause partial or complete damages on nearby structures. Vibration levels, excitation frequencies, site conditions, distances from the blast's source and structural characteristics for blast loading are fundamental features to measure the effects of structures against blast loading. This load type produces ground vibrations and air blast pressures on nearby structures. Because ground vibrations reach to foundations of structure before air blast pressure, accentuating the importance of the blast ground motion can be more critical for dynamic response analysis of structural systems rather than investigating the total effect caused by blast type loading on structures. Past research studies on blast ground motions are plenty in numbers. Only a few are referred here to examplify [1–10].

The effects of spatial variation of earthquake ground motion on dynamic response of large structures such as bridge, stadium, nuclear power plant, dam etc. are still being investigated by many researchers [11–17]. The influence of wave passage effect, incoherence effect, site effect and wave attenuation of earthquake excitations varying on the different support points of small structures, such as elevated fluid tanks, towers, short-span highway bridge and multi-stored buildings, are

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insignificant. Therefore, the spatial variation of earthquake ground motion for small structures is generally not necessary to take into account in the analyses. However, blast ground motion is a load having to be paid attention for short-span structures. Although the distances between short-span structures' support points are very small when compared to long-span structures, the amplitude throughout high frequency content of blast ground motion undergoes rapid changes over short distances. The reason is the close distance of short-span structures from the source center and drastically changing shock load characteristics. Therefore, spatial variability characteristics of blast ground motions are essential in order to be able to expose its effects on short-span structures more accurately. Regrettably, only few studies in the literature were carried out to investigate the effects of spatial variability of blast ground motions on structural performance [18–21]. Many studies dealing with highway bridges have been carried out in the literature. A few studies by Wilson and Jennings [22], Shinozuka [23], Lou and Zerva [24], Mwafy et al.[25] and [26] are mainly conducted to the seismic earthquake response analyses of highway bridges to spatially varying ground motion.

It is hardly expected that blasting would have any significant effect on a bridge near the quarry where blasting is commonly performed. It is more common to include some small buildings, like 1-2 story houses, some old churches, etc. Also, commonly used vibration standards do not include the effect of blast-induced ground motion on bridges (there are no limit values of peak particle velocity and predominant frequency for bridges, regarding the effect of blast induced ground motion). Based on above mentioned description, because of lack of studies regarding to blasting effect on short-span bridges, especially, the current study concentrates on the effect of spatially variation of blast ground motion on stochastic dynamic response of short-span highway bridges. Thus, the purpose of this study is to carry out a three-dimensional stochastic dynamic analysis of a highway type bridge when applied spatially varying blast ground motion. ANSYS [27] is utilized to perform the required numerical application of stochastic dynamic analysis. The three different charge weights with the three different charge centers are utilized, and shaded image contours and one standard deviation (1σ) as well as power spectral densities (PSD)of the responses of the highway bridge are computed as numerical calculations.

2. Spatial variation of blast ground motion

Due to the high frequency content and rapid attenuation, the spatial variation of blast ground motion significantly affects the dynamic response of short-span bridges. Although the importance of spatial variation of blast ground motion for short-span structures is well understood, very limited knowledge is available on this topic because of the scarcity of available literature [18–21].It is essentially known that the wave propagation of blast ground motion will be affected not only by its phase due to the wave passage effect, but also by the wave amplitudes, frequency contents and duration due to geological cases. Practically, the spatial variation of ground motion is usually described by a phase shift function and a coherency loss function. A few studies demonstrated the effects of both coherency loss and phase shift of spatial ground motions are significantly effective in rock media, and in particular, phase shift effects are more significant to flexible structures while coherency loss effects are more pronounced to stiff structures. Because of the short distance to the explosion center, blast ground motion normally has very high frequency contents, thus the effect of rock mass discontinuity on its attenuation and spatial variation will be significant [18–20].

In this section, the spatial variation of blast ground motion using the random vibration theory is implemented. The stochastic responses of short-span highway bridge are given by the power spectral density (PSD) and one standard deviation (1σ) of defined. The structural response can be decomposed into pseudo-static and dynamic parts, i.e., $u = u_s + u_d$ when there is a differential excitation at the structure supports. As displacement of blast ground motion is very small, the quasi-static response of the structures to blast ground motion will be small. However, spatial variation of blast ground motion effect could be very significant on dynamic responses of structures.

Spectral density function of dynamic component of structural response is given by

$$S_{u_{d_i}}(\omega) = \sum_{j=1}^{n}\sum_{k=1}^{n}\sum_{l=1}^{r}\sum_{m=1}^{r} \varphi_{ij}\varphi_{ik}\Gamma_{lj}\Gamma_{mk}H_j(-\omega)H_k(\omega)\, S_{\ddot{u}_{g_l}\ddot{u}_{g_m}}(\omega) \tag{1}$$

where n is the number of degree of freedom and r is the number of restrained degree of freedom; $[\phi]$ is the eigenvectors, $[\Gamma]$ represents the modal participation factor, $S_{\ddot{u}_{g_l}\ddot{u}_{g_m}}(\omega)$is the cross spectral density function of ground accelerations between supports l and m, $H(\omega)$ is the frequency response function, respectively. Frequency response function is given by

$$\mathrm{H}_k(\omega) = \frac{1}{\omega_k^2 - \omega^2 + 2i\xi_k\omega_k\omega} \tag{2}$$

where ω_k is the modal circular frequency and ξ_k is the modal damping ratio. The variance of structural response component is given by

$$\sigma_{u_{d_i}}^2 = \int_{-\infty}^{\infty} S_{u_{d_i}}(\omega)d\omega \tag{3}$$