Spatio-Temporal Frequency Variation Analysis Of Vehicle Bridge Interaction System: Considering Higher Bridge Frequency Interaction

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Vehicle-Bridge Interaction (VBI) dynamics characterizes the time varying condition of the vehicle and the bridge, which is critical in monitoring a railroad bridge. In a railroad bridge, the mass of the vehicle that crosses the bridge is large with determined directions, the interaction between such moving vehicle and the bridge need to be appropriately understood. Thus, so far, researchers have been profoundly studied on the VBI system by numerically solving the time varying system equations. When focused on the spatio-temporal frequency variation, a larger deviation occurs when the natural frequency of two systems (i.e. the vehicle and the bridge) are close. Further, the researchers have found analytically and numerically that the trends of the variation are affected by the frequency ratio of those systems. However, most of the studies focused on the interaction between the first natural frequencies of each system, with little attentions made on the interaction due to higher bridge frequencies. Therefore, this paper performs a spatio-temporal frequency variation analysis for the VBI system in higher bridge vibration modes. Herein, the bridge is modeled as a simply supported beam using the assumed modes method. Two vehicle models are developed, a quarter-car model and a more complex half-car model. For both vehicle models, vehicle properties are designed such that its first natural frequency is close to the second bridge natural frequencies. To fully investigate the frequency variations, the static analysis are performed firstly by manipulating the mass ratio and the tire stiffness. Then, pseudo-dynamic analyses are followed to examine the dynamic effect. Note that the bridge in this study is assumed to be smooth, with humps introduced in the pseudo-dynamic analyses to yield impact forces. To interpret the results, Frequency Amplification Ratio (FAR) is introduced, which evaluates how spatio-temporal frequency varies with respect to the original frequency. The results showed that the FAR is highly determined by the initial frequency ratio, at which the interaction occurs between the systems; i.e. if the bridge's second natural frequency is lower than the vehicle's frequency, the bridge's FAR is lower than 1 in most of the cases. However, unlike the case when the first bridge mode interacts with the first vehicle mode, where FAR varies in parabolic trends, the higher mode effects induced the fourth order polynomial trends. Moreover, at mid-span, FAR becomes larger than 1, with its bandwidth changes with vehicle and bridge properties. Such results implies that the first mode approximation may mislead the bridge vibration characteristics. Pseudo-dynamic analysis was performed to validate the static results. The short time Fourier transform is performed to capture the spatio-temporal frequency variation, along with peak-picking algorithm to evaluate the bridge mode shapes at the target frequencies. Comparing the with static analyses, similar frequency variation aspects, within the tolerable frequency resolution, are achieved. The results of the presented study show that understanding the spatio-temporal frequency variation in VBI system is important, especially the higher modes interaction, for ensuring the sustainability and serviceability of the railroad bridges.