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STUDY OF THE GROUP EFFECTS ON THE VIBRATION SERVICEABILITY OF SLENDER FOOTBRIDGES

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Summary

It is well known that when a group of pedestrians crosses a lightly damped footbridge in-unison at its fundamental frequency, large vibrations are to be expected. In an attempt to estimate the increase in the footbridge vibrations due to a group of people as compared to that generated by a single pedestrian, this paper presents a study of two footbridges subjected to different numbers of pedestrians moving at various speeds. Various vibration evaluation parameters such as peak acceleration, maximum transient vibration value (MTVV) and vibration dose value (VDV) were computed for each measured vibration record. The frequency-weighting functions from different standards were used for the computation of each evaluation parameter. To assess the group effects for each case, an enhancement factor was defined as the ratio of the particular vibration evaluation parameter when a group of pedestrians crossed the footbridge divided by the same from only one pedestrian. This study showed the relative consistency between the results of the tests on the two structures. However, it became evident that the variations of the enhancement factors are not consistent with those reported in the existing literature.

Keywords: dynamics; response; group effects; enhancement factor; vibration evaluation; vibration dose value; frequency-weighting functions; field testing

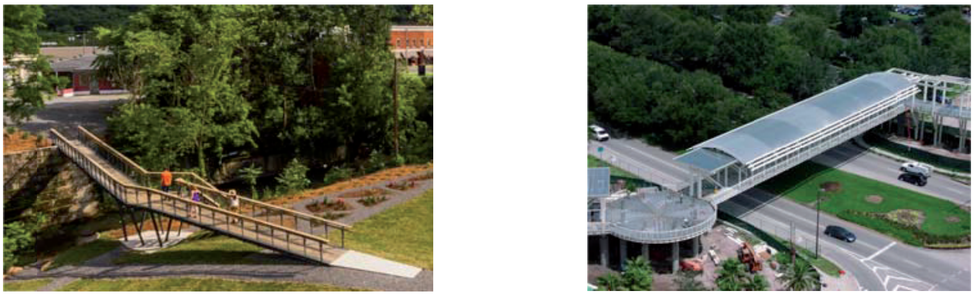
1. Introduction

High strength of modern construction materials has allowed architects and engineers to design slender footbridges that are aesthetically appealing and economical but can be susceptible to excessive vibrations due to pedestrian movements. Large vibrations of footbridges due to pedestrians crossing the structures in unison at their fundamental frequency which resulted in catastrophic failures are well documented. It is clear that when a group of people crosses a footbridge, the resulting vibrations are larger than those from one pedestrian. The majority of the results in the available literature have focused on the analytical studies of vibrations due to randomly moving pedestrians. Therefore, this paper presents the results of a series of field tests and evaluations to measure the vibration magnification when a group of people crossed two different footbridges. Both footbridges are made of steel structure; however, Footbridge One has a short span (13.6 m) and Footbridge Two has a relatively longer span (61 m).

Different vibration evaluation parameters were used to study the footbridge group effects. These include the peak acceleration (a_p), maximum transient vibration value (*MTVV*) which represents the peak one-second running root-mean-squared (RMS) of weighted acceleration, and vibration dose value (*VDV*). Enhancement factors are defined as the ratio of these vibration evaluation parameters when a group of pedestrians cross the footbridge divided by the same due to one person. The frequency-weighting functions representing sensitivity of human body to vibrations, from different standards were used for computing the frequency-weighted acceleration.

2. Description of the Footbridges

Figure 1 shows the photos of the two footbridges used in this study. Footbridge One consists of I-shaped beams along the two side supporting a timber deck. The beams are in turn supported by steel columns. Footbridge Two uses two trusses supported by steel columns. The trusses support the bridge deck which consists of metal deck with cast in place concrete topping.



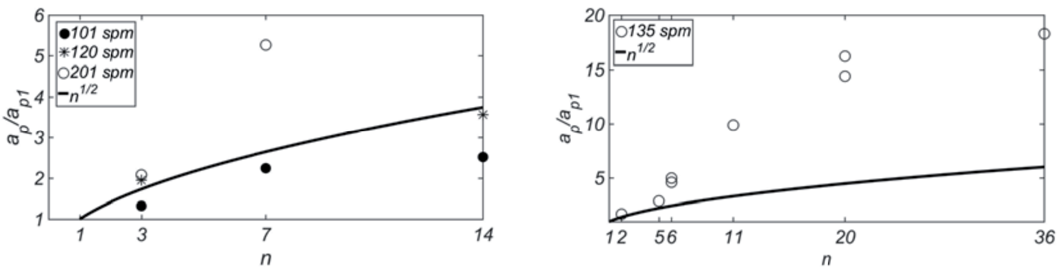
(a) Footbridge One *(b) Footbridge Two*

Figure 1.The two footbridges used in this study

3. Group Effect Studies

Group effects on both footbridges were studied by conducting a series of tests with various numbers of pedestrians crossing the structure, at different speeds and computations of vibration evaluation parameters from the resulting vibration records (a_p, *MTVV, and VDV*). Footbridge One had a fundamental frequency of 3.35 Hz and a damping ratio of about 0.8%. Up to 14 volunteers crossed Footbridge One at different speeds. For Footbridge Two, which had a fundamental frequency of 2.25 Hz and a damping ratio of 1%, up to 36 pedestrians were used. For each test, the enhancements factors for a_p, *MTVV*, *VDV* were computed.

Figure 2 shows the enhancement factors of a_p/a_{p1} for both footbridges along with the available recommendation in the literature ($\sqrt{n}$). As shown in figure 2(a), the test subjects crossed the Footbridge One in unison at 101 spm (steps per minute), 120 spm, and 201 spm (fundamental frequency of footbridge). On Footbridge Two, people walked at 135 spm (fundamental frequency of footbridge) as shown in Figure 2(b).



(a) Footbridge One *(b) Footbridge Two*

Figure 2 a_p/a_{p1} enhancement factors

4. Summary and Conclusions

This paper presented a study of the group effects on the serviceability of two slender footbridges. It was found that the measured enhancement factors when people moved in unison on the footbridges at their respective fundamental frequencies are significantly larger than the recommended values in the literature for the case of random movements of pedestrians. It was also observed that the enhancement ratios for when people move in unison at the footbridge fundamental frequency is close to the number of people for smaller group sizes. This reduces with an increase in group size, which can be attributed to an increase in the footbridge damping due to the human-structure interactions and the fact that it is more difficult for a larger group to move in unison.