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EXPERIMENTAL INVESTIGATION OF THE VIBRATION SUSCEPTIBILITY OF FOOTBRIDGES FOR SUBCRITCAL VIBRATION MODES

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Summary

A lot of slender and/or long span footbridges display vertical vibration modes with natural frequencies below the frequency range that is specified to be critical by various guidelines. The presented study aims at assessing the susceptibility of vibration modes in a sub—critical frequency range within the scope of serviceability aspects. The assessment is based on vibration tests on 2 slender long-span footbridges which revealed modes and frequencies below normal footfall rates. During the vibration tests accelerations with a significant participation of the sub-critical modes were observed in particular for randomly and slowly walking occupants on the bridge deck though the overall acceleration levels were within acceptable values. In addition vibration tests with an intended resonance-like excitation of the relevant modes were performed. The measured dynamic response was then qualitatively compared with the calculated dynamic responses for which methods of current guidelines and experimentally determined Dynamic Load factors for sub-critical footfall rates and for subharmonics have been applied. Based on this comparison the relevance of sub-critical vibration modes for normal loading and vandalism was assessed.

Keywords: sub-harmonic excitation; sub-critical frequency range; in-situ vibration tests

1. Introduction

With regards to the susceptibility to human induced vibrations, current guidelines define only a medium risk for vertical vibration modes of footbridges with corresponding natural frequencies below 1.6 Hz resp. 1.7 Hz. However for a proper assessment of the vibration behavior the question about the occurring accelerations in those fundamental vertical modes remains. This is due to various considerations, for example about the probability of an intentional resonance-like excitation or the likeliness of passages with longer footfall rates (< 100 steps/minute) - which can still cause a resonant-like excitation - but also the subharmonic content from an excitation with higher footfall rates.

2. Observations at very slender footbridges

The first example is a 217m long arched footbridge with a free span of 156 m. Ambient vibration tests were performed to determine the relevant vibration modes and the structural damping. The fundamental bending modes are at 0.78 Hz (lateral bending) and 1.09 Hz (vertical bending). The second vertical bending mode was also identified with a sub-critical natural frequency of 1.33 Hz. It appears that the natural frequency for the 1st lateral bending mode is in range of a subharmonic of 1st torsional mode. Amongst others the load case were 1Person walks with a conducted footfall frequency (metronome) to cause a resonance-like excitation for the relevant modes has been investigated.

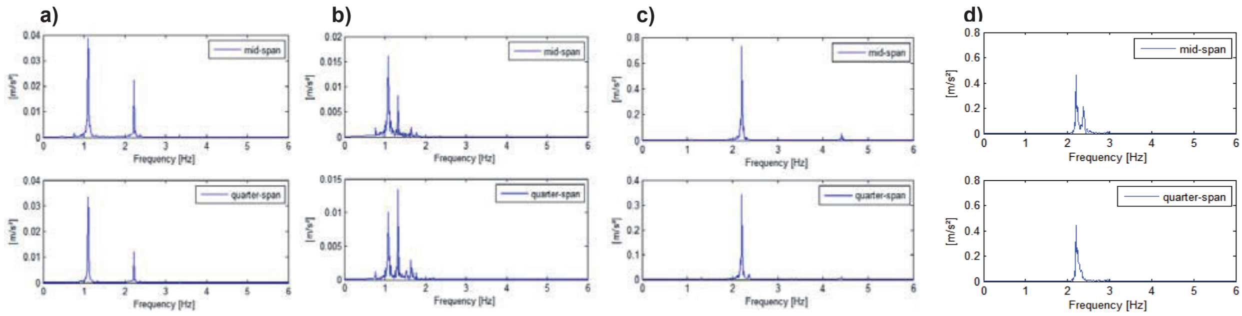

Fig. 1. FFT Spectra of the measured accelerations at mid- and quarter-span – a) for 1 person walking with 66 steps per minute b) with 79 steps per minute and c) 132 steps per minute d) 143 steps per minute

A direct comparison of the theoretically assumed DLF with the experimental results is not possible due to transient effects of the vibration state – which strongly depend on the structural damping ratio, the probabilistic p on the location of the excitation. Still for the Bridge Example A the contribution of the vibration modes from the theoretical model can be compared with the obtained frequency spectra for the examined load cases. Using the DLF as described in [1] & [2] the dynamic response of the examined bridges can be analytically determined for the applied footfall frequencies. Figure 2 shows the obtained FRF from the modal parameters, the harmonic force function in the frequency domain for the harmonic loadings as well as the resulting displacements and accelerations.

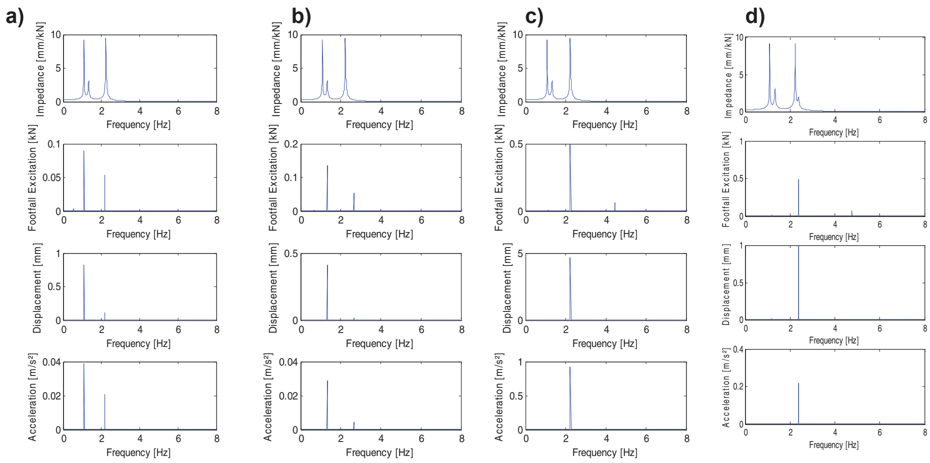

Fig. 2. Analytically determined dynamic response for the above described examined load scenarios

3. Conclusions

Vibration tests at very long and slender footbridges have been performed with the premises to assess the vibration susceptibility of vibration modes with natural frequencies <1.6 Hz. During these tests a dynamic response of these sub-critical vibration modes contributing to the overall dynamic behaviour during random use of the bridge could be identified. Especially for activities with low footfall rates the contribution of these modes was found to be dominant hence the resulting acceleration levels remained very small. Depending on the structural damping ratios of the relevant vibration modes an intended resonance like excitation is possible, again with no significant acceleration levels. The experimental data showed very little contribution from subharmonic excitation, so it is hard to determine whether this is due to forced (quasi-static) excitation, ambient influences or the direct footfall.

References

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[2] ŽIVANOVIĆ S., PAVIC A., REYNOLDS P., "Probability based prediction of multi-mode vibration response to walking excitation", Engineering Structures, Vol. 29, pp. 942-954, 2007.