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A simplified formulation for vibration serviceability of footbridges

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Summary

Vibration problems in structures and particularly in footbridges are growing fast due to a combination of effects like new lightweight construction materials and/or design of slender structures. This paper presents a general view about the procedures to tackle the problem of pedestrian-induced vibration of footbridges. Attention is focused on investigating some simplified formulations presented in the literature and applicable to beam-like footbridges. Limitations in applying these simplified formulations were elucidated and a new formulation is proposed to overcome such limitations. A computer program specifically developed for the analysis of moving pedestrians in footbridges was employed in numerical exercises to check the performance of the formulations, demonstrating the accuracy of the proposed formulation.

Keywords : footbridges; design codes; serviceability; vibration

Abstract

Pedestrian-induced vibration of footbridges has been recognised as a design problem for a long time. One of the earliest codes presenting guidelines to tackle this problem was the British code BS 5400. In this code, it is recommended that footbridges having fundamental frequencies below 5 Hz should be checked for vibration serviceability. The problem was characterized as a serviceability issue since the human body is very sensitive to vibrations and the level of vibrations causing disturbance to pedestrians is very unlikely to cause damage to the structure.

Being designed solely for the conveyance of pedestrians, such structures may present low natural frequencies, within the common range of pacing rates of pedestrians. The load produced by pedestrians during walking can be considered to be periodic and may be represented by means of Fourier Series, in which the first term or harmonic has a frequency which is the pedestrian pacing rate. The subsequent harmonics have frequencies which are multiples of the pedestrian pacing rate. Therefore, footbridges having natural frequencies within the range of the first or higher harmonics of the excitation may present resonance problems. Furthermore, low damping ratios have been measured in footbridges and the association of these two factors, that is, potential resonance and low damping, may result in lively structures.

Actually this is not only a theoretical possibility since case reports of footbridges presenting excessive vibrations are presented in the literature and, in some cases, remedial measures against excessive vibration were adopted.

Attention is also given to vibration serviceability of footbridges in other codes and guidelines. In addition, several guidelines are presented in the literature as a result of research carried out in this area. However, the approach adopted in these codes and guidelines diverge, this being an indication of the uncertainty in dealing with the problem.

In this paper, an analysis is carried out aiming to clarify the different approaches dealing with the pedestrian-induced vibration of footbridges. Attention is focused on analysing simplified formulations applicable to beam-like footbridges. Results obtained in numerical simulations using a computer code specifically developed for the analysis of vibrations of footbridges produced by pedestrians, together with the results of pedestrian tests in lively footbridges from earlier publications were employed in this analysis. Inconsistencies and limitations of some formulations were explored.

In an attempt to overcome the limitations discussed above, the following formulation is proposed to estimate peak accelerations in beam-like footbridges:

$$a_{max} = \omega_o^2 \, y_s \, \alpha_i \, \Omega_d \, k_a \qquad (1)$$

In this expression, α_i is a dynamic load factor, ω_o is the fundamental frequency in rad/s, y_s is the static deflection in the midpoint of the main span (in meters) for a concentrated load of 700 N (the weight of the pedestrian) applied at this point, Ω_d is a dynamic response factor, and the configuration factor k_a was obtained from numerical exercises by applying Eq. (1) to estimate accelerations in single span and in two span footbridges. Eq. (1) is actually a modified version of the expression presented in the British code, incorporating the advantages of other formulations presented in the literature.

The accuracy of Eq. (1) was checked by comparing the estimated accelerations using this formula with those calculated by a computer program. The program, in turn, was checked by comparing its results with the theoretical response of simple beams to moving harmonic loads.

A comparison was also made of the performance of all simplified formulations for single span and two-span beam-like footbridges of equal span length. The dynamic load factor was adjusted in each formulation to make it possible to compare the estimations of peak acceleration In the cases examined, the proposed formulation was more accurate than the other ones in estimating peak accelerations.