VIBRATION PERFORMANCE OF TWO FRP FOOTBRIDGE STRUCTURES IN THE UNITED KINGDOM

Stana ŽIVANOVIĆ
Associate Professor
University of Warwick
Coventry, United Kingdom
s.zivanovic@warwick.ac.uk

Xiaojun WEI
Research Fellow
University of Warwick
Coventry, United Kingdom
x.wei.3@warwick.ac.uk

Justin RUSSELL
Research Fellow
University of Warwick
Coventry, United Kingdom
j.russell.3@warwick.ac.uk

J. Toby MOTTRAM
Professor
University of Warwick
Coventry, United Kingdom
j.t.mottram@warwick.ac.uk

Summary
Footbridges are increasingly made of fibre-reinforced polymer (FRP) composites due to advantages they bring, such as high-strength and light-weight nature of the material, fast installation and low maintenance costs. It is often argued, however, that the low mass of these structures might lead to high sensitivity to vibration, especially when the low mass is coupled with a low natural frequency and/or low damping ratio for one or more modes of vibration. This paper investigates dynamic behavior of two FRP footbridges — each having a deck that is made of pultruded units that were interlocked and bonded together. The two structures have different spans (51.3m vs 16.9m) and structural systems (suspension vs simple beam) resulting in distinctly different natural frequencies. Six vibration modes were identified for the suspension bridge in the frequency range up to 5Hz, whilst there was one mode only for the simple beam bridge. Comparison of the vibration behavior under human-induced excitation, however, revealed that they exhibit similar responsiveness to walking excitation due to the suspension footbridge having higher mass per unit length and the beneficial role of nodal points in the vibration modes. A walker reported being more sensitive to vibrations of the suspension bridge, which is, given the vibration frequencies in question, opposite to the (well known) effect on a standing person. This paper demonstrates that even extremely light (e.g. the simple-beam) bridge can exhibit satisfactory vibration performance.

Keywords: FRP composites; footbridges; modal testing; vertical vibration; walking; vibration perception

1. Introduction
The large-scale use of high-strength and light-weight fibre-reinforced polymer (FRP) composite materials in construction offers an exciting opportunity for developing a more sustainable and resilient built environment. Before FRP composites can become part of the wider solution for developing more sustainable and resilient infrastructure, future research has to advance the currently limited understanding of how these low-weight structures perform when subjected to dynamic actions. This paper describes experimental work conducted on two footbridge structures made of glass FRP composite material. First modal testing to determine the dynamic properties of the two structures is presented. This is followed by description and analysis of structural response to walking-induced dynamic loading.
2. Dynamic Properties of Two Footbridges

Footbridge 1 is a suspension structure that crosses a road via a single, 51.3m long, span (Fig. 1a). It is supported by 2 steel cables and 20 steel hangers. Footbridge 2 is a more than two times shorter simple beam structure that crosses a picturesque river valley in a single span of 16.9 m (Fig. 1b). The deck of both bridges is made of pultruded glass FRP products named Composolite and produced by Strongwell. Ambient testing was conducted on Footbridge 1 whilst the impact modal testing was performed on Footbridge 2.

![Footbridge 1](image1.jpg) ![Footbridge 2](image2.jpg)

Fig. 1. a) Footbridge 1, b) Footbridge 2

The results of the modal testing reveal that the suspension footbridge has a relatively high density of the vibration modes in the frequency region up to 5Hz, whilst the shorter simple beam bridge has one mode only in the same frequency region. Comparison of the fundamental natural frequency of the two structures with those measured for footbridges made of conventional materials reveals that the frequency values are similar between the two groups, assuming similar span lengths. Interestingly, the damping ratios for vibration modes of the two FRP structures are similar to those typical of the top 50 percentile in RC structures.

3. Vibration Response to Walking-Induced Dynamic Loading

The two footbridges were exposed to excitation by a single person walking to metronome controlled pacing frequencies. An example of the acceleration record measured at the midspan of Footbridge 2 when walking at pacing rates from 2.0Hz to 2.6Hz is shown in Fig. 2.

![Acceleration Record](image3.jpg)

Fig. 2. Response at TP5 to crossing Footbridge 2

Analysis of the response of the two footbridge to walking-induced dynamic force revealed that, albeit these two structures have distinctly different natural frequencies, the peak response to walking-induced excitation was very similar, i.e. about 1m/s². Footbridge 1 has 6 vibration modes that can be considered to be excitable by one of the first two harmonics of the walking-generated force, while only the fundamental vibration mode of Footbridge 2 is strongly excitable by (second) forcing harmonic. Still, the second bridge experiences similar vibration level – this is primarily due to much lower mass of this structure. On the other hand, despite the responses being similar in magnitude, subjective feeling of the walker was that this largest response was more perceptible on Footbridge 1 – most likely due to the effect of the vibration frequency on the vibration perception.