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DESIGN, CONSTRUCTION AND DYNAMIC ANALYSIS OF A LABORATORY-SCALE FRP COMPOSITE FOOTRBIDGE

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Summary

Pedestrian loading on flexible structures such as footbridges, grandstands and lightweight floors is an area, which is receiving significant attention from the research community of late. Of particular interest is the interaction between the pedestrian loading and the structural response of the loaded structure.

This paper describes the design and dynamic analysis of a laboratory-scale FRP composite footbridge, constructed to study human-structure interaction. The bridge was specifically designed to have a natural frequency within the range excitable by human walking. It will be used to investigate the interaction between loads produced by walking and running pedestrians and the vibration of the structure which they are traversing.

Keywords: pedestrian loading; human-structure interaction; vibration serviceability; spring-mass-damper; structural damping; natural frequency

1. Introduction

Vibration serviceability of lightweight or long span structures has emerged as a critical design consideration in recent times. While many models have been proposed to simulate the loading applied by pedestrians, this loading is influenced by the vibration response of the structure being traversed.

Models which account for this interaction between pedestrians and the flexible structures upon which they are walking have been identified as crucial to better simulation of pedestrian-induced loads. However, calibration of these models has proven difficult. In particular, the exact contribution of crossing pedestrians to both the stiffness and damping characteristics of a coupled bridge-pedestrian system is unknown.

2. Design & Construction Process

The bridge was designed to consist of two main beams, with regular cross bracing, all constructed from GFRP, manufactured by the authors. This provided a grid, which supported a plywood deck. There is a recess provided at midspan to support a force plate. Access and egress (walk-on, walk-off) platforms are provided at each end of the bridge. The span of the bridge can be adjusted by positioning of the supports, with a range of spans available from 6.5m to 8.0m.

Finite element modelling of the bridge in ANSYS estimated the natural frequency of the empty structure to be 3.98Hz for a span of 6.5m and 2.97Hz for a span of 6.5m. As the presence of a pedestrian on the bridge was likely to lower the natural frequency, these values were deemed suitable for the study of human-structure interaction. The FE model was further updated following the static and dynamic analysis to yield optimum comparison with the measured values. Figure 1 shows the completed structure.

Figure 1. (a) Completed Laboratory Scale FRP Composite Footbridge (b) with person at midspan

3. Dynamic Analysis

The measured natural frequency of the empty bridge, for the 8.0m configuration was 2.97Hz, compared to 2.73Hz predicted by the FE model. For the 6.5m span, the values were 3.98Hz and 4.08Hz respectively. When an 80kg static mass was placed at mid=span of the bridge, the measured natural frequency for the 8.0m span reduced from 2.97Hz to 2.19Hz, as expected. For the 6.5m span, the frequency reduced from 3.98Hz to 2.94Hz.

The measured response showed a damping ratio for the empty bridge of 1.45% for the 6.5m configuration, with a value of 1.30% for the 8.0m clear span. When the 80kg mass was placed at mid-span, the values increased to 1.48% and 1.80%, representing an average increase in structural damping of just under 16%.

4. Influence of Stationary Humans on Dynamic Response of Footbridge

The dynamic response of the bridge with human test subjects present was also measured in order to assess the influence of the humans on the dynamic properties of the now coupled system.

5.1 Effect of Person Standing at Midspan on the Natural Frequency of the Bridge-Person System

The presence of an inert 80kg mass at the centre of the bridge span reduces the natural frequency of the first vertical mode shape from 2.97Hz to 2.19Hz. When the pedestrian with a mass of 80kg stood at the centre of the span, the frequency further reduced to 2.11Hz. Therefore, although the pedestrian and the inert mass had the same mass, they both affected the natural frequency of the bridge slightly differently. The natural frequency, therefore is not just contingent on the mass of the pedestrian, but also upon their stiffness contribution.

5.2 Effect of Person Standing at Midspan on the Structural Damping of the Bridge-Person System

The structural damping was shown to be heavily influenced by the presence of a human on the bridge. While an 80kg inert mass caused a 19% increase in damping, a person of the same mass standing caused an increase of 157%. In terms of the magnitude of structural damping ratio, it increased from 1.30% for the 8.0m span empty structure to 2.91% for the same span, with one person standing at the centre of the bridge.

5. Conclusions

An 11m long glass fibre reinforced polymer composite laboratory scale footbridge has been constructed in AIT to investigate human-structure interaction. The measured static and dynamic response of the empty structure correlated well with the results obtained from a finite element model and show that the bridge is suitable for studying pedestrian-induced vibrations. The structural damping ratio increased from 1.5% to 1.8% with the addition of the 80kg inert mass. Moreover, the dynamic properties were further altered by the presence of a human test subject of equivalent mass (frequency = 2.11Hz; damping ratio = 2.91% - an increase of 157%). The person had a greater influence on the natural frequency and a considerably greater impact on the structural damping. Both support the idea that pedestrians contribute to the stiffness and the damping of the coupled bridge-structure system and must be considered as such when attempting to simulate pedestrian loading on flexible structures.