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Vibration Performance of Footbridges Established via Modal Testing

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Abstract

Modal testing techniques are increasingly used to obtain the dynamic properties of civil engineering structures for the subsequent calibration of the finite element (FE) models used for their design. This makes it possible to improve future analyses of the vibration performance of such structures. These coupled experimental and analytical FE model updating techniques, which have developed rapidly in the 1990s, originated in the mechanical and aerospace engineering disciplines. They have been applied successfully to the dynamic testing of medium sized full-scale structures, such as long-span floors, footbridges and chimneys, as well as to larger structures such as suspension and cable-stayed bridges.

A footbridge may experience disturbing vibrations while in use, and the aim of this paper is to investigate the effects of its layout and handrails on the natural frequencies, determined to be the sole most important factor which governs the vibration serviceability of the footbridge. The investigation is based on modifications to FE models calibrated against site tests of two prototype footbridges which could be considered as potentially lively.

The two footbridges tested were both single-span structures, the first a composite steel-concrete pre-cambered beam, and the second a single span stressed ribbon structure.

The first footbridge consisted of a 2.16 m wide concrete deck connected to a 0.225 m deep pre-cambered steel box girder. The structure had a span of 19.90 m and was supported on a pair of elastomeric bearings at each end. All four bearings were different and it was expected that they had different relative stiffnesses in the vertical and horizontal directions. Steel handrails, in the form of short independent panels made of hollow section components, were attached to the deck and followed its vertical profile.

The stress-ribbon footbridge consisted of a 34 m long by 1.8 m wide single span catenary shaped prestressed concrete slab which was fixed at the abutments. Steel handrails made of continuous hollow box sections were firmly attached to the slab. The depth of the deck was 160 mm thickened locally towards the ends. An asphalt topping of 12.5 mm constant thickness was placed on the top of the slab.

The two test structures were used to investigate potential improvements in their vibration performance. Attention was focused on the investigation of the natural frequencies caused by changes in the design and modelling of the structural layout and its components. This could be useful as a design strategy when performing frequency tuning exercises, frequently required when designing footbridges so that the critical frequency ranges of the excitation may be avoided.

In the case of the pre-cambered footbridge, modal testing carried out with and without handrails attached to the structure demonstrated only a small influence on the dynamic properties of the structure. The fact that the handrails were made of short independent panels eliminated any

stiffening potential, which is one of the ways of promoting frequency tuning.

The role of the elastomeric bearings in affecting the fundamental frequency of vibration was also investigated parametrically. The camber of the structure may induce some stiffening arching action, provided that there is a sufficient restraint to horizontal displacement at the elastomeric bearings. The predominant stiffening influence of the arching action is on the fundamental mode. This can be understood by the shape of this mode, implying that there are larger horizontal displacements, and consequently the mobilisation of the axial stiffening since these displacements are restricted to some degree by the bearings. The conclusion was that the use of the horizontal (i.e. shear) stiffness of the bearings, in association with a pre-camber may be an effective tool for changing the natural frequencies of pre-cambered footbridges.

In the case of the stressed ribbon footbridge, the handrails had a more significant influence on the vibration characteristics of the structure. Since the handrails were continuous, followed the catenary shape of the deck and were firmly attached to it, they contributed to both bending and axial stiffness of the structure. Both the deck and the handrails were modelled using rigidly connected beam elements. Indeed, an initial attempt to model the structure by including the handrails simply as an added mass resulted in a poor correlation between the experimental and FE results for some of the modes.

In order to investigate in more detail the role of the catenary shape on the modal properties, an FE model of the footbridge was prepared as if it were rectilinear. This resulted in a complete change of the modes of vibration, which were then similar to those of a straight beam, as expected. The first mode presented a natural frequency of 0.9 Hz and was symmetric, as opposed to the first anti-symmetric mode of 2.3 Hz measured on the actual footbridge. The difference in value between these fundamental frequencies shows the considerable effectiveness of a catenary shape in increasing the natural frequencies of footbridges.

The main conclusions from the experimental results and numerical exercises carried out were:

- A good representation of the dynamic behaviour of the stressed-ribbon structure was obtained by modelling continuous handrails as a frame rigidly attached to the deck. In the two test cases, an increase of up to 20% in the fundamental frequency was obtained when the contribution of the continuous handrails was taken into account.

- The best results in terms of frequency tuning were obtained by changes to the layout of the structures. A combination of a cambered or catenary profile together with horizontal restraint was shown to be useful for increasing natural frequencies, since it induces some stiffening by arching action.