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Experimental assessment of damping coefficients in short-span filler-beam railway bridges

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Abstract

Railway bridges are structures were the dynamic effects due to the passage of traffic could reach significant values, especially for speeds higher than 200 km/h, essentially due to the resonance phenomena originated by the periodic loading associated with the passage of regularly spaced axle groups of the trains. In resonance situations, the amplitude of the dynamic response of the bridges is very dependent of the damping of the train-track-bridge system including its interfaces. In framework of the In2Track2-WP5 project, experimental data of field tests performed in four filler-beam bridges of the Portuguese Railway Network were used. To evaluate the damping coefficients, the logarithmic decrement method and the Prony method were applied using the free vibration responses of the acceleration records due to passing trains. Ambient vibration tests allowed the identification of the modal parameters of the bridges, namely, the natural frequencies and modal configurations. The results of this work may contribute to future revisions of EN1991-2.

Keywords: damping coefficients, filler-beam railway bridges, logarithmic decrement method, prony method.

1 Introduction

Structural damping is an important characteristic of railway bridges that affects the structural performance, especially for bridges with trains circulating at speeds greater than 200 km/h. At these speeds dynamic effects can reach significant values due to the resonance phenomena originated by the periodic loading associated with the passage of regularly spaced axles groups of the trains. In resonance situations, the amplitude of the dynamic response of bridges is very dependent of the damping of the train-track-bridge system including its interfaces.

Damping may increase for larger amplitudes due to nonlinear effects and increased friction mechanisms in the bridge and track components. EN1991-2 [1] defines lower bound values for damping, ranging from about 0.5% to 2.5%, depending on bridge type and span length. Background research reported in ERRI D214/RP3 [2] showed that many bridges presented damping coefficients exceeding 5%, especially for local modes of vibration of deck elements. Therefore, further experimental characterization is required particularly for bridge typologies not directly covered by the Eurocode.

In framework of the In2Track2-WP5 project, experimental data of field tests performed in four filler-beam bridges of the Portuguese Railway Network were used. To evaluate the damping coefficients, the logarithmic decrement method and the Prony method were applied using the free vibration responses of the acceleration records due to passing trains. Ambient vibration tests allowed the identification of the modal parameters of the bridges, namely, the natural frequencies and modal configurations.

2 Methods

The experimental tests were performed in four railway bridges (Braço do Cortiço, Canelas, Cascalheira and Vale da Negra) located on the Northern Line of the Portuguese Railways. Figure 1 shows the tested bridges consisting in simply supported spans varying between 7m and 12m.

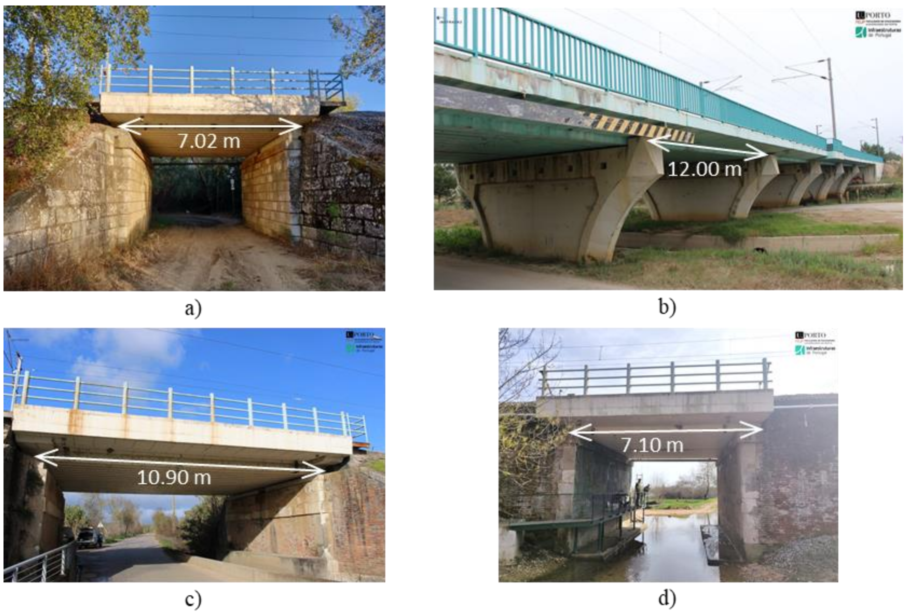


Figure 1: Railway bridges: a) Braço do Cortiço underpass; b) Canelas bridge; c) Cascalheira underpass; d) Vale da Negra underpass

The experimental tests involved ambient vibration tests and dynamic tests under railway traffic.

The ambient vibration tests were performed under ambient excitation complemented by impacts provided by a non-instrumental hammer, to increase the acceleration levels on the deck. The Enhanced Frequency Domain Decomposition method (EFDD) available in ARTeMIS software [3] was used to identify the modal parameters.

The dynamic tests under railway traffic allowed to estimate the damping based on the free vibration periods after the passage of the train's last bogie. Specifically, the accelerations response of the deck was measured for the passage of Alfa Pendular (AP) train at speeds between 110 km/h and 175 km/h, as well as Intercidades (IC) train at speeds between 100 km/h and 150 km/h. The damping coefficients were estimated for the fundamental modes of vibration using the logarithmic decrement method or the Prony method.

The logarithmic decrement method involves the application of a bandpass digital filter (Chebyshev Type II) to the acceleration record centred on the vibration mode's frequency, followed by the adjustment of an exponential function to the maximum values of the filtered record:

$$a[t] = C \cdot e^{-\xi \omega t} \quad (1)$$

where C is a constant value, ξ is the damping coefficient and ω is the angular frequency related to the vibration mode.
The Prony method allows the decomposition of the acceleration record in set of exponential decaying sinusoids representative of each frequency of interest, to estimate a complex exponential model of the form [4]:

$$a[t] = \sum_{i=1}^{n} A_i e^{-\xi_i \cdot \omega_{0,i} \cdot t} \cos\left(\omega_{o,i}\sqrt{1-\xi_i^2} + \phi_i\right) \quad (2)$$

where n is the number of complex exponentials of interest, A_i the amplitude of the i^{th} exponential component, ξ_i the damping coefficient, $\omega_{0,i}$ the angular frequency, and ϕ_i the phase angle.

The logarithmic decrement method is used when the free vibration record presents a clear damped sinusoid, due to the contribute of a single mode of vibration (Figure 2). Otherwise, Prony method is used when the free vibration record presents the contributes of two or more coupled modes of vibration, as visible in Figure 3, namely in the Fast Fourier Transform (FFT) spectrum and the correspondent breathing effect in the time-domain record.

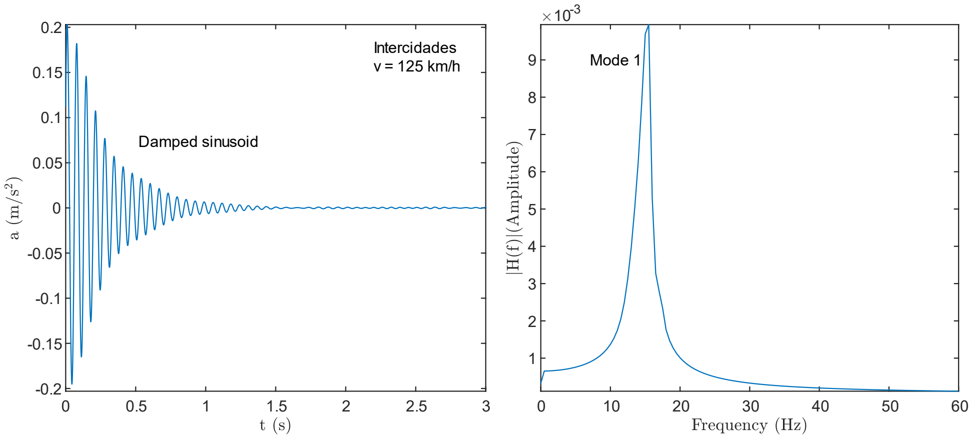


Figure 2: Time record and corresponding FFT of a free vibration record with a single mode contribution

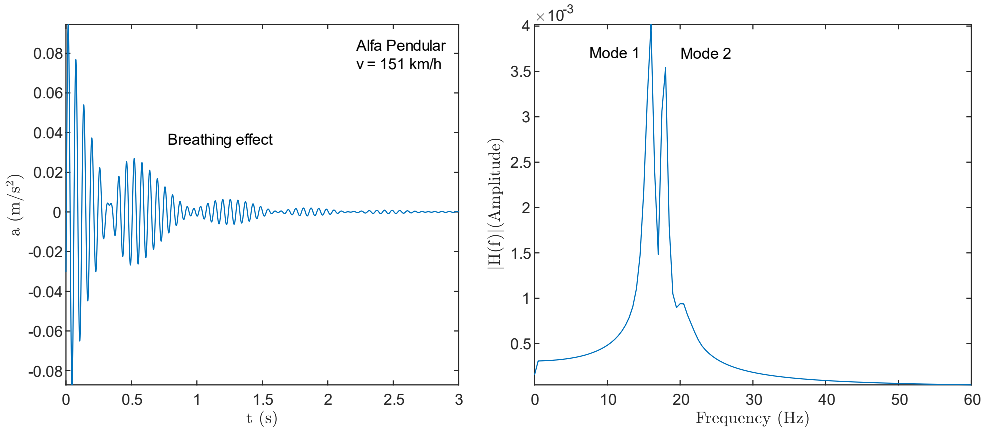


Figure 3: Time record and corresponding FFT of a free vibration record with a double mode contribution

3 Results

Table 1 shows the fundamental modal configurations and corresponding natural frequencies for all the tested bridges. For bridges with span lengths of approximately 7m (Braço do Cortiço and Vale da Negra) the fundamental frequencies are ranged between 15Hz and 18Hz. For bridges with span lengths between 10m and 12m (Canelas and Cascalheira) the fundamental frequencies are between 8Hz and 10Hz. The fundamental frequencies values as a function of the span length of the bridges are presented in Figure 4a. The fundamental frequencies values are within the range proposed by EN1991-2 [1].

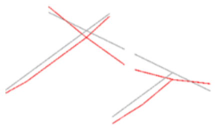
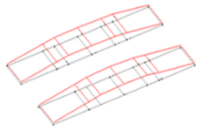
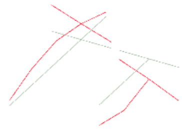
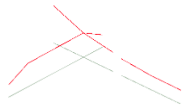
	Braço do Cortiço underpass	Canelas bridge	Cascalheira underpass	Vale da Negra underpass
Mode shape				
Frequency [Hz]	18.01	8.70	9.50	15.24

Table 1: Modal parameters of the tested bridges

Based on the application of the logarithmic decrement method and the Prony method to the studied bridges, it was possible to construct a database with the experimental damping coefficients for each span length, considering the passages of AP and IC trains. Figure 4b presents the damping coefficients values in function of the span lengths of the bridges, where is clearly visible that the damping values are often larger than the lower limit defined by EN1991-2 [1] for filler-beam bridges.

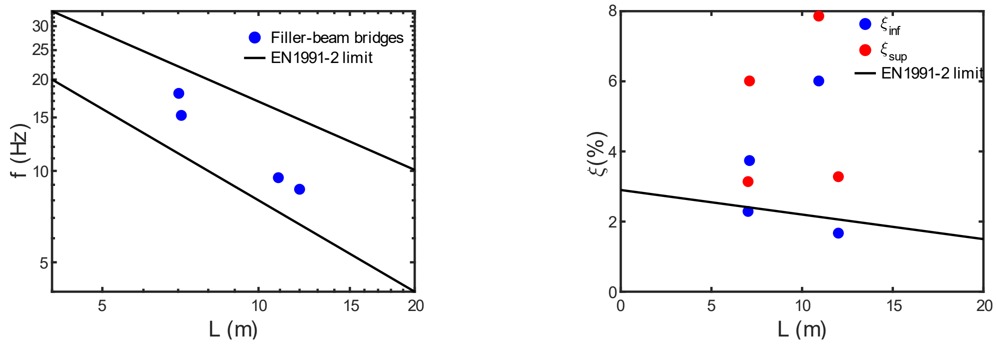


Figure 4: a) span length (L) vs fundamental frequency (f); b) span length (L) vs damping coefficient (ξ)

4 Conclusions and Contributions

This paper described the experimental assessment of damping coefficients in four railway bridges of the Northern Line of the Portuguese Railways. Based on ambient vibration tests and by application of the EFDD method, the fundamental frequencies and mode shapes were identified. From the analysis of the results, it can be seen that the fundamental frequencies for this type of bridges are between 8Hz and 18Hz, depending on the span length, and within the range proposed by EN1991-2. From the results of the dynamic tests under railway traffic, most of the damping coefficients estimates, for distinct bridges and different type of trains, are higher than the limit proposed by EN1991-2. The free vibration records due to the trains passage allowed to identify accurate damping values, which values are higher than the Eurocode. This is related to the higher vibration levels induced by the trains in comparison with the ambient vibration levels. This study aims to contribute for the future review of the damping coefficient values used for the dynamic analysis of filler-beam railway bridges.

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