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Influence of boundary conditions on the natural frequencies and damping of timber beams of sweet chestnut

Gonzalo Cetrangolo [a], Soledad Rodríguez [b], Aitor Rodríguez [b], Vanesa Baño [a,*]

[a] Institute of Structures and Transport (IET), Facultad de Ingeniería, Universidad de la República, Julio Herrera y Reissig 565, CP. 11300 Montevideo, Uruguay
[b] Forest and Wood Technology Research Center (CETEMAS), Finca Experimental La Mata, C.P. 33820 Grado, Asturias, Spain

HIGHLIGHTS

- Dynamic properties of Spanish sawn chestnut timber.
- Influence of three different support conditions on the natural frequencies and on the damping.
- Relationships between experimental and numerical natural frequencies.
- Continuous Wavelet Transform to obtain damping ratio.

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ABSTRACT

Steel supports designed for timber structures do not always correspond with the theoretical constraints considered in the structural design. The degree of fixation provided by the supports affects the dynamic properties of structural systems. The objective of this work is to analyse the influence of different support conditions on the natural frequencies and on the damping properties of *Castanea sativa* Mill. timber beams. Dynamic vibration tests were performed on eight $40 \times 100 \times 2500\ \text{mm}^3$ chestnut timber beams and signal processing was applied to obtain the natural frequencies and the damping ratio. Each beam was considered in three support systems: one simulating the free–free condition, and the other two were obtained by supporting them on different steel fasteners. Experimental natural frequencies were then compared to numerical values. The experimental natural frequencies did not show statistically significant differences between the two steel supports analysed. For the first flexural frequency, experimental values showed statistically significant differences with respect to the numerical results from pinned–pinned condition for the two steel supports studied. The values obtained of damping ratio were slightly higher than the values presented in the Eurocode 5 for beams with joints.

1. Introduction

Timber floors and footbridges are considered light-weight structures, where the design is mainly affected by serviceability limit states. The effects of humans on these structures are an important vibration source because added mass affects the natural frequency of the structures. Vibrational analysis is thus particularly important in these light-weight structures in order to decrease resonance risk and to enhance comfort while walking, since humans perceive these vibrations [18].

The Eurocode 5: part 1–1, [4] establishes the need for special analysis when the fundamental frequency of the structure is less than 8 Hz, because walking discomfort increases at lower frequencies. The Spanish Standard related to loads on bridges IAP-11 (Ministerio de Fomento IAP, 2011) establishes the risk range of resonance for footbridges as between 1.25 Hz and 4.60 Hz. Experimental tests of simply supported slender timber footbridges in Spain has shown fundamental frequencies to be slightly higher than those obtained theoretically, mainly due to the effect of the boundary conditions and the damping parameters considered [7].

The type of steel fastener most commonly used in Spain to support timber footbridges is shown in Fig. 1, named support A. This kind of support is considered as pure hinged in the static and dynamic structural calculations, although the degree of stiffness generated by this fastener is unknown and, therefore, the influence of this support in the dynamic responses is unknown.

Some commercial software for structural analysis allow the introduction of damping coefficients for a complete structural dynamic analysis. These parameters vary depending on material

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* Corresponding author.
E-mail addresses: gonzaloc@fing.edu.uy (G. Cetrangolo), srodriguez@cetemas.es (S. Rodríguez), aitorforcelledo@gmail.com (A. Rodríguez), vanesab@fing.edu.uy, vbanho@gmail.com (V. Baño).

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Fig. 1. (a) Picture of a typical timber footbridge in Spain; (b) detail of the steel fastener (support A).

type and boundary conditions, among other factors. Eurocode 5 [4] states different values of modal damping ratio (ξ) for different type of structures.

Dynamic excitation is commonly used to estimate stiffness, bending strength and the relative position of defects in timber beams, and to evaluate the real behaviour of the boundary conditions of beams [9,19]. [11] studied the resonance frequencies of timber guardrail beams to evaluate the influence of the different degrees of fixation between beams and posts. Other authors investigated the vibration behaviour of timber floors under different boundary conditions and different type of connectors [6,21,12]. Similar studies have also been carried out on materials other than wood in light-weight structures where the effects of supports on the structural dynamics are important [16]. Different signal processing techniques are commonly used to study the dynamic response of structures. The Continuous Wavelet Transform (CWT) method has been used for several years to extract signal features in the time domain, as well as to analyse the frequency content of signals, known as frequency slice [8,22].

The main objective of this study is to evaluate the deviation of the steel supports commonly used in Spain in timber footbridges (support A, Fig. 1) with respect to the ideal pinned–pinned condition, and to evaluate the damping ratio. In order to isolate the problem, the support was not analysed on the footbridge structure, but on single timber beams. Experimental and numerical results of natural frequencies from sweet chestnut (*Castanea sativa*, Mill.) beams are compared for the support A and for another support type designed as pure hinge (support B, Fig. 2). Also, the relative difference between the experimental natural frequencies of suspended beams and numerical natural frequencies for an ideal free–free condition were studied. The damping ratio for the different experimental support conditions is estimated. This information provides design engineers with baseline knowledge of the real behaviour of the steel supports commonly used in timber footbridges.

2. Materials and methods

To analyse the influence of the different support conditions on the natural frequencies and damping ratio, static and dynamic tests were performed on eight timber beams. Sweet chestnut (*C. sativa* Mill.) beams from Spain were studied, with nominal dimensions of 40 × 100 × 2480 mm^3, conditioned to 65 ± 5% of humidity content and 20 ± 2 °C.

2.1. Global modulus of elasticity

In order to obtain the static modulus of elasticity of the beams, four-points bending tests were performed using a universal testing machine, model ELIB-30-MD2W from Ibertest (SAE. Ibertest, Madrid), according to EN 408 [3]. They were tested as simply supported with a span of 18 times their height. The local modulus of elasticity (E_m) was determined according to Eq. (1). The adopted value of shear modulus (G) for all cases was $E_m/16$, since no experimental data was available. The load was applied according to the previously mentioned standard and the density, ρ (kg m^{-3}) was determined:

$$E_m = \frac{3al^2 - 4a^3}{2bh^3\left(2\frac{w2-w1}{F2-F1} - \frac{6a}{5Gbh}\right)} \tag{1}$$

where, a, is the distance from the support to the next applied load (a = 500 mm); l, is the span of the specimen (l = 2390 mm); b and h, are the width and height of the cross-section respectively (mm); F_1 and F_2, are the initial and final applied loads in

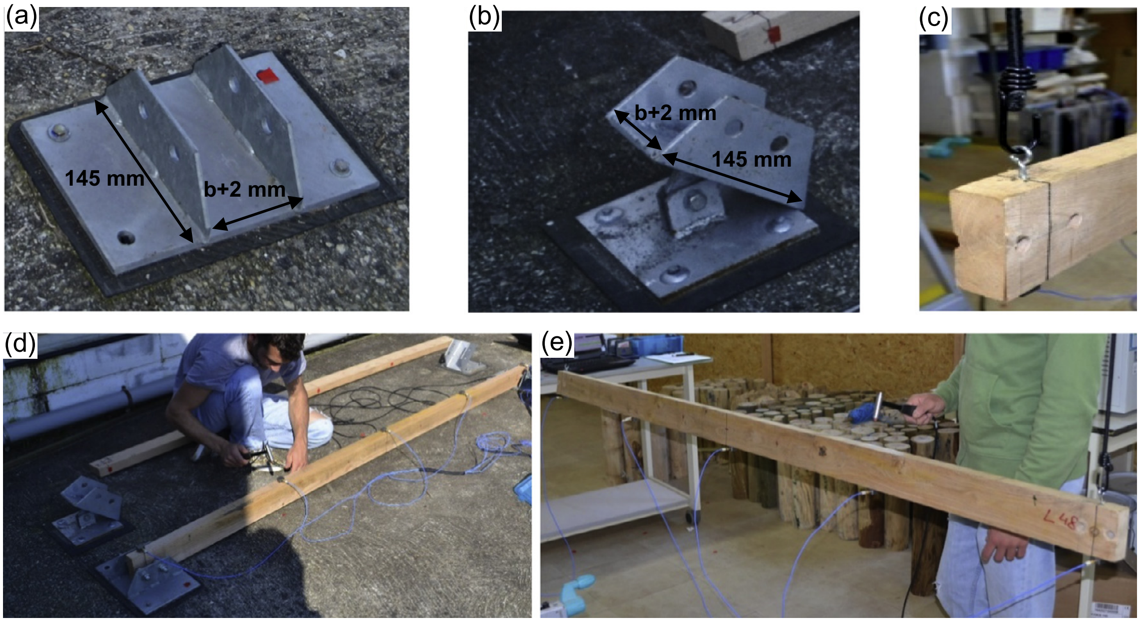

Fig. 2. Details of the: (a) simple support A, (b) hinged support B) and (c) suspended beams; and experimental tests on: (d) supports A and B and (e) suspended beam.