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Analytical, numerical and experimental assessment of vibration performance in timber floors

Daniele Casagrande[a,*], Ivan Giongo[b], Federico Pederzolli[b], Alessandro Franciosi[b], Maurizio Piazza[b]

[a] CNR IVALSA – National Research Council of Italy, Trees and Timber Institute, Italy
[b] Department of Civil Environmental and Mechanical Engineering, University of Trento, Italy

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ABSTRACT

The assessment of the dynamic properties and vibration performance of two full-scale timber floor specimens is presented. The specimen set comprised a Timber-Concrete Composite floor and a Cross Laminated Timber floor. The floors, which are characterized by the same length and mass, are located in two separate five-storey timber buildings constructed in the urban area of Trento (Italy). The assessment was conducted by adopting analytical and numerical methods as well as by performing onsite experimental tests. Mock up samples of the floor specimens were also made and tested in laboratory. Multiple analytical methods that are available in literature were evaluated and compared. The Vibration Dose Value (VDV) method, as proposed by ISO 10137 and BS 6472, was used as reference method for the numerical modelling and the laboratory testing. To determine the VDV, loading associated to human walking was simulated. Dynamic identification tests, where the floors were excited by a modal hammer, were also performed in order to investigate the dynamic properties (i.e. natural frequencies, damping and mode shapes) of the floors. Discussion on the vibration performance of the timber floor typologies studied herein and on the effectiveness of the different assessment approaches (i.e. analytical, numerical and experimental) is provided.

1. Introduction

Because of the low ratio between modulus of elasticity and bending strength of wood, equal to approximately 480 for GL24h [1] glulam grade (as opposed to a value of approximately to 1000 for reinforced concrete), the serviceability requirements for timber floors may be more restrictive than ultimate limit state verifications. The reduced weight of such structural typologies, together with an "increasing flexibility" (i.e. longer spans) necessary to comply with modern space-arrangements and usages, require that vibration performance of floors subjected to footsteps be accurately evaluated.

Differently from the traditional design for gravitational load, the vibration performance of floors may be related to the dynamic response of floor influenced by both the structural (beams floor, deck, etc.) and non-structural (e.g. partition walls, finishing) components associated with excitation due to the human walking. Occupants' tolerance or acceptance level to the annoying vibrations is a subjective matter and can be different from person to person, depending on multiple factors.

Several analytical design procedures for assessing vibration serviceability of timber floors are available [2–7], some of which have been included in standard documents [8–12]. In most cases, the procedures consist of a simplified evaluation of some characteristics of the vibration such as the frequency, vertical displacement, velocity and acceleration. The mathematical expressions are based on fixed assumptions regarding the static scheme, the type of load and the limit values and based on experimental testing performed on selected structural typologies. Because analytical methods are based on simplified calculation of different mechanical and dynamic parameters (e.g. natural frequency, vertical flexibility, maximum vertical velocity and acceleration), vibration performance may be the decisive point in the design of structural floor elements, especially in case of long spans and light weights, conditioning the choice of the size of structural members.

In order to get a more refined evaluation, simplified methods could be replaced with more advanced methods (i.e. numerical modelling) capable of better simulating the real dynamic properties of the structural elements and the effects of external forces. Analytical methods often derive from experimental investigations on a limited number of structural typologies; a direct extension of these approaches to different

* Corresponding author.
E-mail addresses: casagrande@ivalsa.cnr.it (D. Casagrande), ivan.giongo@unitn.it (I. Giongo), federico.pederzolli@gmail.com (F. Pederzolli), alessandro.franciosi@gmail.com (A. Franciosi), maurizio.piazza@unitn.it (M. Piazza).

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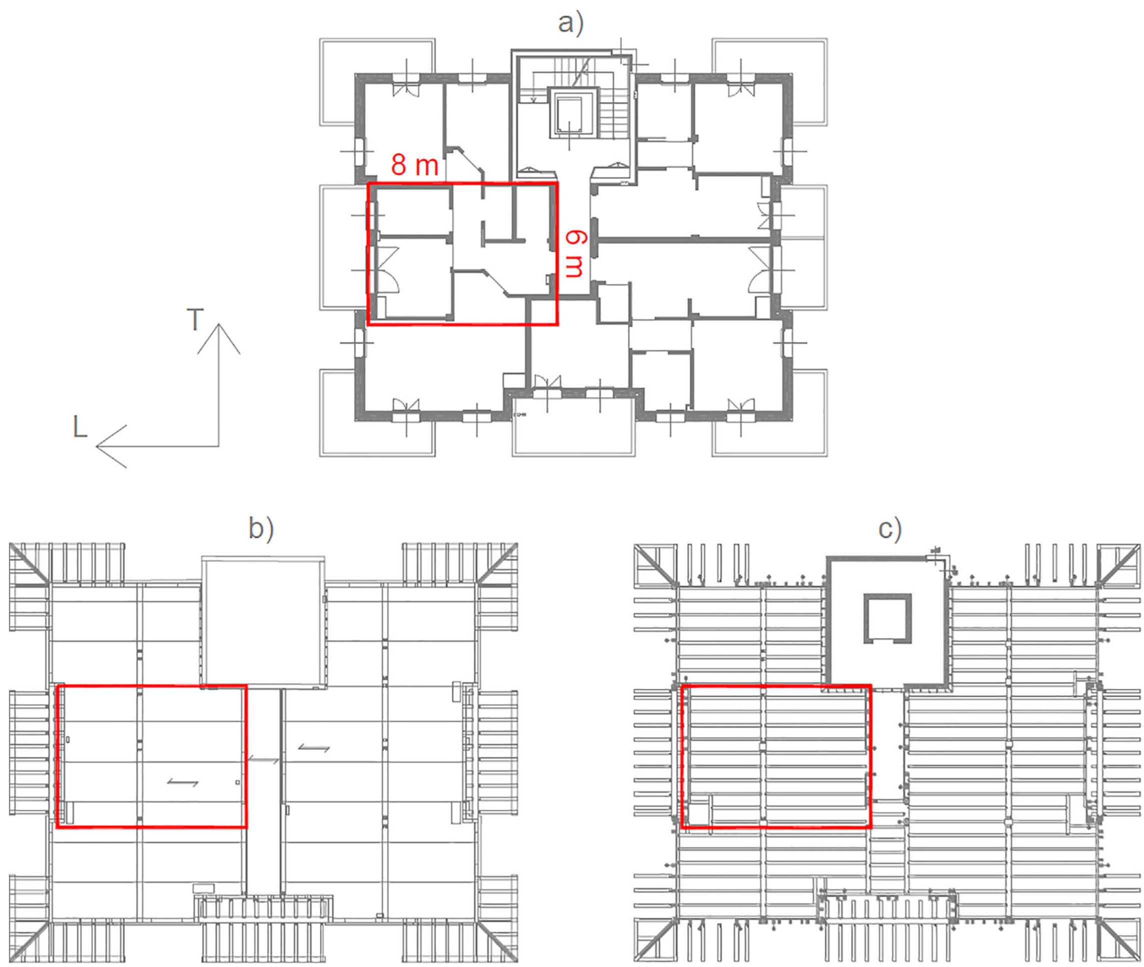

Fig. 1. Architectural, (a) and structural plan of the analysed floor in the South (CLT), (b) and North (LTF), (c) building.

floor types should therefore be verified. Moreover, acceptability criteria seem to be strongly related to the countries where the research works have been conducted and consequently to local building construction traditions and requirements.

A more general approach, regarding all typologies of floors, is reported in [13] based on the processing of the vertical accelerations due to human walking on the floors. The Root Mean Square (RMS) and the Vibration Dose Value (VDV) of the signals are suggested as reference parameters and different limit values are reported as function of the vibration source frequency (only for RMS method), the vibration direction (vertical or horizontal) and the type of buildings where vibration occurs. The VDV is obtained by integrating the vibration level over a time period of intermittent vibration, whereas the RMS is commonly adopted for a full resonant continuous response. Simplified approaches can be used in the evaluation of RMS [14] since walking load cannot be represented by a single frequency sinusoidal load, whereas in the evaluation of VDV weighting frequency curves are used to filter acceleration signals according to [15]. In [16] only the VDV method is reported. However, since vibrations induced by footsteps can be defined as intermittent rather than continuous, the VDV method seems more adequate than the RMS method to evaluate the floor performance. The VDV can be determined knowing the floor response in terms of acceleration from either experimental testing or numerical modelling [17,18]. Alternatively, simplified analytical formulations for the evaluation of VDV can be found in [16,19].

An extensive research campaign on the vibration performance of wood based floors that are common Canada, has been carried out by Hu [20,21]. The campaign includes laboratory testing and field testing on newly constructed floors prior to use. The measure of vertical deflection and frequency of real floors (on-site) and full-scale specimens (in the laboratory) has been related to the subjective evaluation provided by people walking on the floor sections in the form of answers to a questionnaire. A simplified analytical expression has then been obtained as the ratio of the frequency over the vertical deflection. Such expression takes also into account the acceptance level resulted from the subjective evaluations. However, it is worth remembering that Hu's research has been focused on typical structural typologies used in North America and on acceptance criteria adequate for that region. An extension of the results from such research to other types of structure and to other countries should be carefully verified.

This paper focuses on the comparison among different approaches (analytical, numerical and experimental) in the assessment of vibration performance of timber floors. The assumptions, the simplifications and the acceptability criteria of each method are discussed, highlighting differences and similarities. To better illustrate differences and similarities deriving from adopting a diverse range of analysis methods, two case-study floors were selected and their vibration performance was carefully studied.

2. Case studies

Within an international collaboration between the Italian social housing company ITEA S.p.a. and the Canadian Quebec Societè D'Habitation, two five-storey multi-family apartment buildings were built in Trento (Italy) by using two different timber construction systems: light timber frame (LTF) and cross laminated timber (CLT). The floors were made with timber-concrete composite (TCC) constructive system in the LTF building and with CLT panels in the CLT building.