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Damping Assessment of Lightweight Timber Floors Under Human Walking Excitations

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Abstract: Vibrations on timber floors are among the most common serviceability problems in social housing projects. The presence of low damping levels on these floors could cause excessive vibrations in a range of frequency and amplitude that generate discomfort in users. This study focuses on the influence of the damping ratio in the dynamic serviceability of social housing timber floors due to walking excitations. More than 60 human-walking vibration tests were conducted on both laboratory and in-situ timber floors. The floors were instrumented with accelerometers, and fundamental modal damping ratios were estimated by applying Enhanced Frequency Decomposition Domain (EFDD) and Subspace Stochastic Identification (SSI) methods. The vibration dose value (VDV) was used to estimate the dynamic serviceability of floors. The results indicated that timber floors had an impulsive-type vibration response, with fundamental damping ratios between 1.9% and 14.8%, depending on their constructive characteristics. The in-situ floors had damping ratios between two to three times greater than the laboratory floors due to the presence of non-structural elements. Finally, it was possible to demonstrate that the floors with the highest damping ratios reached lower vibration dose values and, therefore, a better dynamic serviceability performance.

Keywords: timber floor vibration; structural damping; operational modal analysis; dynamic serviceability

1. Introduction

Lightweight timber floors are attracting considerable interest in developing countries because of their advantages in terms of sustainability and construction speed. Among the different structural systems in buildings, floors are the only part with which human occupants are in constant physical contact. Therefore, this construction component could become a common source of complaints from the users, generated by the deflections and excessive vertical vibration of the floors while walking on them [1]. This issue, which is becoming more recurrent in diverse construction contexts, has generated a sustained increase in experimental research associated with the dynamic serviceability of timber floors [2].

Damping is one of the most influential factors in the human perception of transient vibration in a timber floor system [1]. This is because damping is an intrinsic property of structural systems that influences oscillation amplitudes and the rate of decay under forced and free vibrations, respectively [1]. Therefore, knowing the level of damping of a timber floor is an essential aspect for structural designers since vibrations tend to be more tolerable in floors that have higher damping [3].

On timber floors, damping comes from two primary sources: the material damping (due to the internal wood anatomy and its defects, such as knots and internal cracks) and structural damping (due to friction in the structural joints and friction between structural and non-structural elements) [3].Under human walking operational conditions, damping can be generated due to the combined effect of different small sources of non-linearity, such as joint friction, interaction between structural and non-structural elements, and the effect of the floor content. Hence, operational damping is not only generated by the intrinsic modal damping of the structure, but also because of all these other energy dissipation mechanisms. In terms of the structural performance, operational damping is more interesting to analyze than intrinsic modal damping, because this is the effect perceived by people.

From the above, it can be deduced that it is not realistic to define a single damping value that is representative of all timber floors. Therefore, each type of construction must be analyzed separately, since any difference in the construction technique or even in the workforce quality could generate different levels of damping [3].

Several studies have been published on damping ratio estimations for different kinds of timber floors constructed in laboratory-controlled conditions. Firstly, investigations focused on studying timber floors that allowed span lengths between 3 m and 5 m to be reached. The floors were generally built with glulam beams [3], an I-joist [4], and a metal web joist [5,6], nailed, screwed, or glued to particleboard or plywood flooring. The damping ratios obtained in these floors had values from 0.82% to 4.78% for the first resonant mode. Subsequently, research focused on studying timber floors that could reach greater span lengths, between 6 m and 8 m. In this way, studies were carried out on timber floors built with laminated veneer lumber beams (LVL) [7], and cross-laminated timber (CLT)-concrete composite slabs [8]. Damping ratios between 0.52% and 1.29% for the first resonant mode were found for these floors. Most of the investigations mentioned above considered idealized support conditions for the floors and did not take into account the interaction with typical in-situ non-structural elements, such as ceilings on the floor's underside and partition walls.

On the other hand, in the last decade, only a few studies have focused on damping ratio estimations for in-situ timber floors. Initially, some researchers analyzed the damping ratios for traditional timber floors in the context of elementary schools [9] and multi-family buildings [10]. These floors generally had a main resistant structure composed of a series of engineered timber beams up to 12 m in length (I-joist, web-joist), oriented strand board (OSB) or plywood boards nailed or screwed on their upper edge to receive concrete topping, and gypsum boards at their bottom edge to increase fire resistance. The damping ratios obtained for the first resonant mode varied between 0.47% and 9.10%. Subsequently, with the rise of industrialized construction, other researchers concentrated on studying the damping ratios of prefabricated timber floors for eight-story timber frame residential buildings [11] and five-story multi-family apartment buildings [12]. These floors generally had a main resistant structure composed of CLT slab panels and glulam beams, which often interacted with sophisticated ceiling systems and lightweight partition walls. The damping ratios obtained for the first resonant mode varied between 3.40% and 8.00%.

Previous work has tended to focus on damping ratio estimations for high-quality timber floors that were constructed in developed countries. The aim of our work is to expand current knowledge on timber floors' damping to lightweight timber floors that are typical in Latin American social housing for low-income families. To the best of the authors' knowledge, no systematic investigation on the damping mechanisms that are activated under human-walking operational conditions has been previously presented in a timber floor context, where softwood species, low-depth timber joists, and unskilled labor are usually used. Such an investigation is presented herein. Generally, this kind of timber floor has a poor vibration performance, which is reflected in the adverse results of satisfaction surveys distributed to users by government institutions. In this context, we focused on the experimental estimation of damping ratios in both laboratory and in-situ timber floors. Different floor spans, support details, types of non-structural elements, and human walking conditions were considered. All the floors were instrumented with accelerometers, and subsequently, operational modal analysis techniques were applied. Finally, some conclusions about the influence of damping ratio levels on the floor vibration performance were made. With the experimental results of this research, it is hoped that this study can contribute to the future calibration of simplified formulas for the vibratory design of these low-cost timber floors, which correlate more complex parameters