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Experimental and analytical study on dynamic performance of timber floor modules (timber beams)

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HIGHLIGHTS

- Experimental and analytical dynamic investigation of six full-scale timber beams.
- Performed impact hammer tests on the timber beams with two different spans.
- The fundamental frequency of all tested beams was above 8 Hz, which is acceptable.
- Analytical models predicted fundamental frequency of all beams within acceptable range of ±5%.
- Mean damping ratio of 6 m and 8 m span beams was 0.65% and 0.58%, respectively.

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ABSTRACT

Timber floors are more susceptible to vibrations and have low impact insulation due to low stiffness and poor damping properties. Recent trends towards long-span and light-weight construction make floor vibration even more critical in satisfying serviceability requirements of floor constructions. This paper presents the results of dynamic tests conducted on timber floor modules (beams) with 6 and 8 m clear spans using an instrumented hammer for floor excitation. Dynamic parameters such as natural frequencies, damping ratios and mode shapes from the tests were evaluated to assess dynamic performance of the beams. The fundamental frequency of the beams was predicted using simple analytical models and good correlation between the test results and predicted values could be obtained.

1. Introduction

Timber is the only truly renewable and environmentally friendly natural building material. Additionally, high strength to weight ratio, ease in workmanship and handling, good fire resistance are some of the properties that make timber attractive for use in construction. However, due to the light-weight nature of timber, timber floors have poor vibration and low impact sound insulation.

Use of timber in residential buildings is widely accepted in Australia. However, its use in non-residential buildings has been limited. The availability of engineered wood products (EWPs) such as laminated veneer lumber (LVL) and glue laminated timber (Glulam) and new generation of adhesives products makes it possible to fabricate composite timber section to meet both strength and serviceability requirements for long-span floors.

Design of long-span and light-weight floor construction may be governed by serviceability requirements rather than strength and dynamic performance is one of these requirements. Therefore, there is a growing need for measurement of dynamic characteristics such as natural frequencies, damping ratios, and mode shapes of floor systems to investigate their behaviour. The serviceability design of flooring systems requires an assessment of the fundamental frequency (or first natural frequency) in order to check the vibration behaviour of the floor and occupant comfort. The following frequency ranges must be avoided for any of the vibration modes:

- Frequency below 3 Hz to prevent walking resonance [1].
- Frequency range of 5–8 Hz to prevent human discomfort [1].

For residential/office floors, a natural frequency greater than 10 Hz shall be targeted [1]. A special investigation is needed if

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the predicted fundamental frequency of the floors is less than 8 Hz. Hence, the prediction of natural frequency, especially fundamental frequency, becomes important for the dynamic assessment of the flooring systems.

The dynamic assessment of the flooring systems is essential in recent times owing to trends towards long-span and light-weight construction. Therefore, there is a growing need for measurement of dynamic characteristics such as natural frequencies, damping ratios and mode shapes of the systems to assess their performance.

Jarnerö et al. [2] assessed vibration behaviour of a pre-fabricated timber floor element in laboratory with different boundary condition and in field at different stages of construction and concluded that on-site conditions have significant influence on the floor damping. Hamm et al. [3], on the other hand, found that timber floors with natural frequencies less than 8 Hz could still have acceptable vibration performance based on in-situ heel drop tests on 50 buildings and 100 floors. Also, a number of other studies have investigated the effect of parameters such as joist spacing, boundary conditions, floor configuration, etc on the modal frequency, damping and mode shape of both timber only and timber-concrete composite floors [4–6].

2. Experimental investigation

Six timber beams made of laminated veneer lumber (LVL) were tested to assess their dynamic performance under the application of impact action initiated with the use of a modal impact hammer. Three of the beams had a clear span of 6 m with identical geometry (L6-01, L6-02 and L6-03) and the remaining three had a clear span of 8 m (U8-01, U8-02 and U8-03). The overall length of the 6 and 8 m span beams was 6.3 and 8.4 m, respectively.

2.1. Geometry of the beams

The cross sectional dimensions for the 6 and 8 m span beams are shown in Fig. 1(a) and (b), respectively. The only differences between the two sections were the depth of the webs and width of the bottom flanges. The top and bottom flanges of all beams were glued and screwed to the web. Further details of the specimens can be found in [7].

The design of both 6 and 8 m span beams were governed by serviceability limit state criteria [7], which is not uncommon for long-span timber beams. The cross-sectional shape of the beams was chosen based on the following advantages:

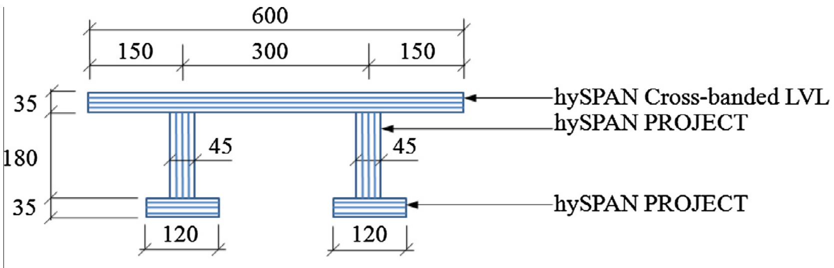
- The space between the webs can be used for the installation of services and acoustic insulation.
- The section has versatile application in the floor construction as it can also be used as upside-down in the modular construction and an additional layer such as concrete topping can be applied on top of it to increase the stiffness of the flooring systems which in turn reduces vibration and static issues.
- It is more stable compared to the "T" and "I" sections.

2.2. Material properties

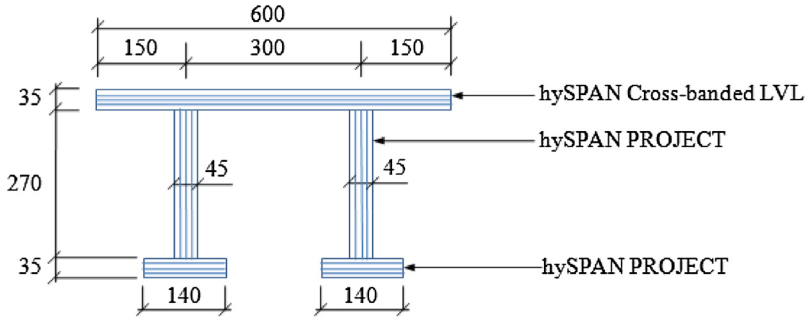
2.2.1. LVL timber

Two types of LVL, hySPAN Cross-banded LVL for the top flange and hySPAN PROJECT LVL for the webs and bottom flanges, were used in the fabrication of the beams. Flat-wise properties for the top and bottom flanges and edge-wise properties for the webs, which replicate the orientation of the flanges and webs in the beams, were tested.

A summary of the results (mean values) for individual components of the beams is presented in Table 1. The dynamic performance of the systems is highly sensitive to the modulus of elasticity (MOE) and the density of the timber beams. Minimum of eleven samples were tested for each component to find MOE of the LVL and the flanges were found to have higher variability in the MOE values compared to the webs. Bottom flanges had maximum coefficient of variation (CoV) of 12.3%. The density of the components showed no significant variation within individual components and among the components [7].



(a) 6 m timber beam



(b) 8 m timber beam

Fig. 1. Geometry for 6 and 8 m span timber beams (mm).