RESEARCH ON VIBRATIONAL PERFORMANCE OF TIMBER FLOORING SYSTEMS AT NAPIER UNIVERSITY IN THE UK

(Presentation for Session WG1 of COST Action E55 – Analysis of failures
and malfunctions related to violations of serviceability limit states)

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Abstract: Undue floor vibrations in residential buildings can cause inconveniences to the occupants. This serviceability issue is not satisfactorily addressed in the current British Standard BS5268 and Eurocode 5 (EC5) and still requires further modifications of the existing design guidelines in the National Annexes to EC5. An extensive research programme has been conducted at Napier University to get a better understanding of vibrational problems and to investigate the effects of varied parameters on dynamic performances of timber floors. This paper reports the ongoing research programme and present preliminary results.

1. INTRODUCTION

Timber framed houses have become more popular nowadays in the European housing market due to their rapidity, economy and environmental excellence, where light-weight timber floors, fabricated in particular with engineered I-joists, are largely used. However, vibrations in these floors often demote service performance. The EC5, together with the National Annexes (NAs) for different member countries, provides guidelines for limiting vibrational parameters (BSI 2004a; 2004b). However, there are still some influential factors which have not been fully included in these guidelines.

An extensive research programme has been conducted at Napier University in the UK to experimentally and numerically study the effects of configurations on vibrational performances of light-weight timber floors with I-joists, e.g. floor span, joist dimensions and arrangements, decking materials and connecting details, blocking, self-weight and boundary conditions. The measured parameters include modal frequencies and shapes, damping ratios, unit load deflection, etc. Finite element modelling is being carried out to analytically simulate the dynamic behaviour of the floors. This paper reports the ongoing research programme, which is closely related to objectives of Working Group 1 (WG1) of COST Action E55, and present typical preliminary results.

2. DESIGN GUIDES

The Eurocodes have been established as pan-European standards to harmonise design criteria so as to form a uniform basis for design, research and development within the European Union. Individual National Annexes are enclosed for design to consider local demands of different member countries. EC5 Part 1-1, Design of timber structures, is sub-divided into two main categories: ultimate limit states (ULS) and serviceability

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limit states (SLS). The former control the stability and load capacity of structures, and the latter are used to avoid impairments of buildings, such as excessive floor vibrations.

The design criteria with respect to timber floor vibrations are part of the SLS in EC5 and are based on the research work of Ohlsson (Ohlsson 1982; 1988). They require the fundamental natural frequency to be greater than 8 Hz and the unit impulse velocity response and unit point load deflection of the floor to be limited. Nevertheless, different countries use different approaches to ensure satisfactory dynamic performances of timber flooring systems. Regulations in the NA alter the corresponding design rules (BSI, 2004b) or fully replace these rules (Kevarinmäki, 2005). Further research attempting to control the vibrations of timber or composite floors has been carried out by a number of scientists around the world (Hu, 2002; Toratti et al., 2006).

3. EXPERIMENTAL INVESTIGATIONS

Full scale timber flooring systems were tested in laboratory conditions. The influence of varied parameters on the dynamic response was investigated, including supporting conditions, decking materials, methods of fixing decking boards to joists, joist dimensions and arrangements, blocking between joists, floor weights and dimensions. Attention was paid to the influence on unit point load deflections and natural frequencies together with modal shapes and damping ratios. The construction process of a large scale test floor is shown in Figure 1.

(a) A timber frame was fixed to the concrete floor using nails.

(b) Supports were fixed onto the timber frame using screws.

(c) The floor structure was constructed before placing decking boards.

(d) The floor, decked with OSB and supported in two edges, was finished.

Figure 1 — Construction of a large scale timber floor

In order to measure the unit point load deflection of the floor, dial gauges were placed at floor centre and the mid-points of each edge. Steel sections were used to apply a load of 1 kN at the floor centre (Figure 2). For calculating the net deflection of the structure, the dial gauge readings at the edges in the direction perpendicular to the span need to be deducted.

Figure 2 — Setup for a deflection test

An operational modal analysis technique was used to investigate the modal parameters. The floors were artificially excited by surface-brushing. Sensors, mounted on a floor surface (Figure 3), converted the vibrational motion of the structure into electrical signals, which were recorded by a data recorder and transferred to a laptop. The professional modal analysis software ARTeMIS Extractor was used to finally process the signals by applying Fast Fourier Transform (FFT) and Inverse FFT (IFFT) and to extract the natural frequencies and damping ratios from the captured data.

Figure 3 — Setup for a measurement of the dynamic floor response

4. TEST RESULTS AND FEM ANALYSIS

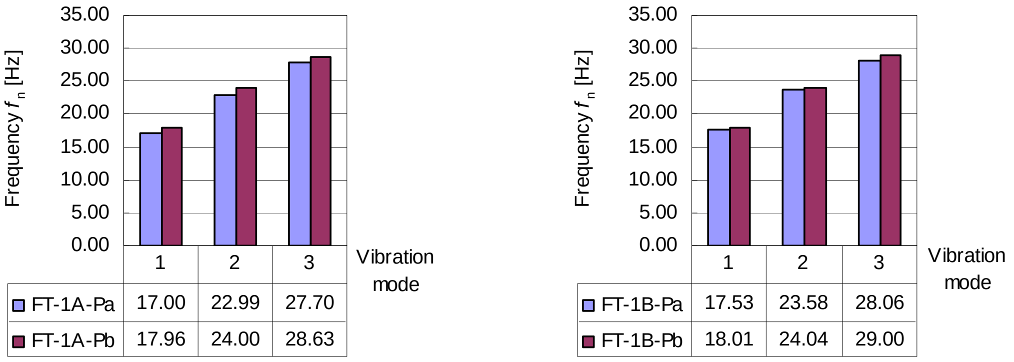
4.1 Effects of Adhesives in Addition to Screws

Floors with the dimensions of L×B = 3.7×4.4 m and 5.0×4.4 m were constructed for investigating the impact of adhesives in addition to screws. Four floors were compared for each span. The floors had a joist spacing of 400 mm and the joist ends were screwed to rim boards. 22 mm particleboard was fixed to the joists using either glue and/or screws at a spacing of 300 mm. The floors were simply supported, laying on top of the supports, or "semi-rigidly" supported by fixing the rim boards to the supports using two screws equally spaced between two adjacent joist ends. The term "semi-rigid" is used to distinguish between the support conditions although the condition semi-rigid may not have been obtained at all. Details of the floor configurations are listed in Table 1.

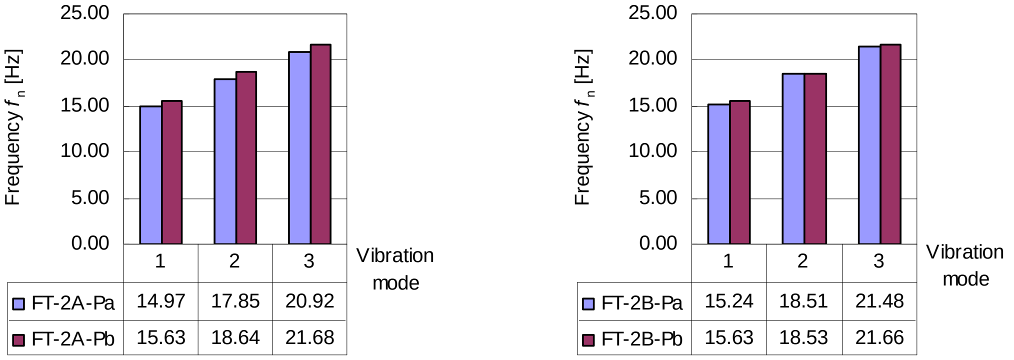
Results are shown in Figures 4 and 5 respectively. As it can be seen, all frequencies could be increased but there is especially a remarkably notable reduction in deflection. The detailed experimental results have been included in another paper (Weckendorf et al., 2007).

Table 1 — Floor configurations

Floor	Size [m]	Configurations
FT-1A-Pa	3.7×4.4	simply supported along two edges, particleboard screwed to joists
FT-1A-Pb	3.7×4.4	simply supported along two edges, particleboard glued + screwed to joists
FT-1B-Pa	3.7×4.4	semi-rigidly supported along two edges, particleboard screwed to joists
FT-1B-Pb	3.7×4.4	semi-rigidly supported along two edges, particleboard glued + screwed to joists
FT-2A-Pa	5.0×4.4	simply supported along two edges, particleboard screwed to joists
FT-2A-Pb	5.0×4.4	simply supported along two edges, particleboard glued + screwed to joists
FT-2B-Pa	5.0×4.4	semi-rigidly supported along two edges, particleboard screwed to joists
FT-2B-Pb	5.0×4.4	semi-rigidly supported along two edges, particleboard glued + screwed to joists

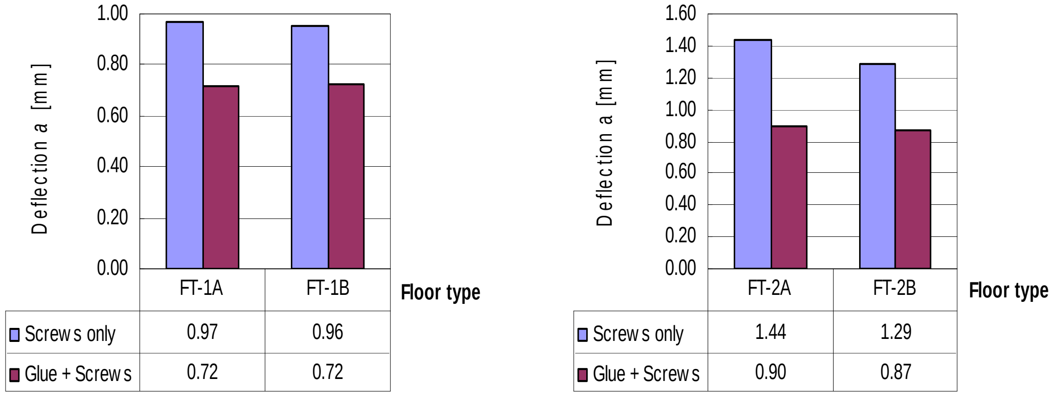


(a) FT-1A-Pa versus FT-1A-Pb **(b) FT-1B-Pa versus FT-1B-Pb**



(c) FT-2A-Pa versus FT-2A-Pb **(d) FT-2B-Pa versus FT-2B-Pb**

Figure 4 — Comparison of the first three bending modes of the floors with four varied configurations for different fixing methods

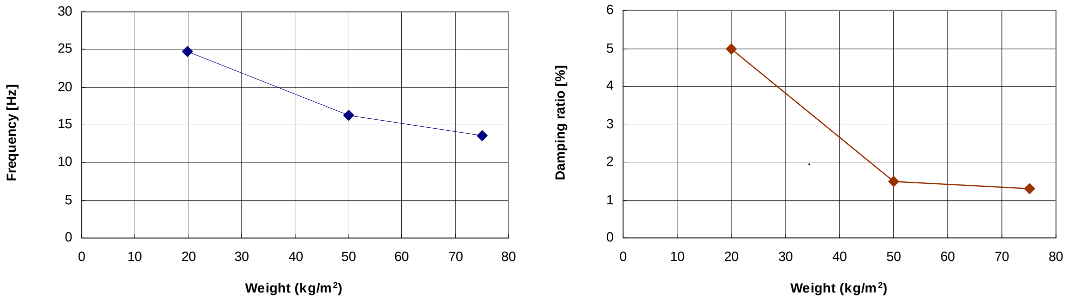


(a) Small scale floor configurations **(b) Large scale floor configurations**

Figure 5 — Comparison of deflections of small- and large-scale floors under varied support conditions for different fixing methods

4.2 Effects of Dead Weight

The impact of mass on the dynamic performance of a small scale flooring structure is shown in Figure 6 with respect to fundamental frequencies and damping ratios. The floor constructed with five I-joists had dimensions of 3.5×2.44 m. The bottom flanges of the joists were fixed to the supports and the joist ends to the rim boards using timber screws. The floor was decked with particleboards, which were connected to the joists using screws spaced at 300 mm. The floor weighed 19.90 kg/m^2. By equally distributing sand bags over the floor surface, the dead weight was gradually increased to 50 and then 75 kg/m^2. It can be seen that the fundamental frequency decreased rapidly with increasing the dead weight of the floor up to 50 kg/m^2 and thereafter this trend became weakened. A similar decrease trend can also be observed in the corresponding damping ratios.



(a) Fundamental frequency versus weight **(b) Damping ratio versus weight**

Figure 6 — Variations of dynamic parameters with floor weight

4.3 FEM Analysis

The floor with a weight of 19.90 kg/m^2 has been modelled using LUSAS FEM software. The measured and predicted frequencies and corresponding mode shapes are compared for the first three modes (see Figure 7). The model will be further calibrated and improved. Nevertheless, the predicted natural frequencies are very close to the measured ones, though the former are only slightly larger than the latter.

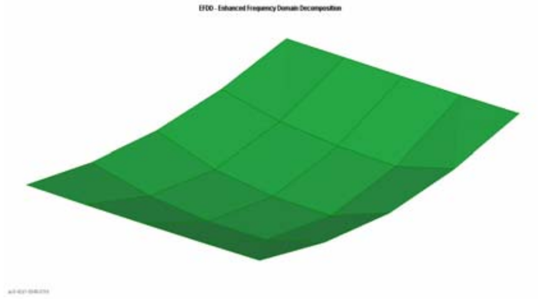
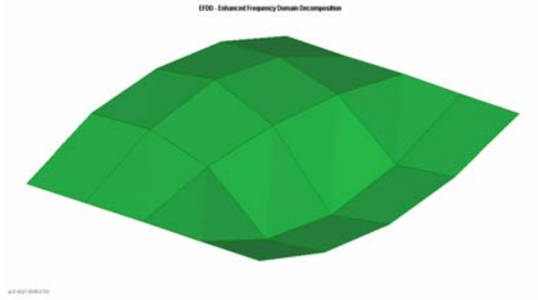
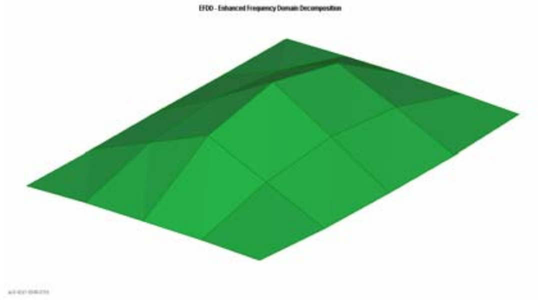
FEM prediction	Measured results
Mode 1	
 $f_{1,\mathrm{FEM}} = 28.2$ Hz	 $f_{1,\mathrm{EXP}} = 24.8$ Hz
Mode 2	
 $f_{2,\mathrm{FEM}} = 31.9$ Hz	 $f_{2,\mathrm{EXP}} = 30.7$ Hz
Mode 3	
 $f_{3,\mathrm{FEM}} = 37.2$ Hz	 $f_{3,\mathrm{EXP}} = 36.3$ Hz

Figure 7 — Comparison of predicted and measured frequencies and modal shapes

5. SUMMARY AND FUTURE WORK

The presented work focuses on the effects of dead weight and arrangements of structural components on the dynamic performance of timber flooring systems. In particular, consideration is given to the unit point load deflection and fundamental frequencies together with the corresponding modal shapes and damping characteristics of the structures. This means that all design criteria in the EC5 and the UK NA to EC5 are appropriately covered. FEM is used for modelling and predicting the dynamic performance of timber flooring structures.

It can be seen that using adhesives in addition to screws can raise the first three natural frequencies and lower the point load deflection, which is beneficial for the dynamic performance of the floors. A higher floor dead weight would lower the fundamental frequencies and the corresponding damping ratios, which is unfavourable. Finite element model can well predict low-frequency modes. Extensive numerical simulations are being carried out at Napier University.

The final aims of this research project are to provide a better understanding of the vibrational timber floor behaviour and to assess the influencing degrees of varied parameters on dynamic response so as to provide guidelines for enhancing structural design. This will include recommendations on appropriate use of damping ratios, structural modifications of existing structures and consideration of effects not taken into account by the currently available standards.

It should be mentioned here that the upcoming STSM of COST Action E55 at VTT Technical Research Centre of Finland will help to further understand the differences in construction, structural assessment and design between the UK and Finland so as to finally enhance the design of timber flooring structures in the two countries.

6. ACKNOWLEDGEMENTS

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