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# Evaluation of floor vibration properties using measurements and calculations

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ABSTRACT

Timber floor constructions are very common in the Nordic countries, for instance in single- and multifamily buildings. But building with wood is increasing in popularity for other building categories and there is wider interest in increasing the span width of wooden joist floors. Static and vibrational performance become crucial for serviceability of timber floors and often limit the design; however, constructors and designers want to increase the floor span width. To meet these challenges, reliable design methods are required and have therefore become a focus in many countries.

This paper presents results from a number of measurements of different joist floor constructions. Parameters measured have also been calculated according to given equations and relevant methods. Both calculations and measurements include 17 laboratory objects and four field objects. The objects represent a huge variety of solutions and therefore a large spread of results. The main reason for the selection of floor solutions was to expand the possibilities and test the methods more than tuning current solutions into satisfactory floor vibration perception.

The data and resulting analysis in this paper highlight benefits and limitations concerning relevant parameters for evaluation of floor vibration perception. According to this work, it is not possible to verify the Eurocode method with respect to accuracy, and the link to perception of floor vibrations is rather low. Another method should be used or developed for the future. Results presented in this paper show that sufficient accuracy may be achieved using parameters from the Hu and Chui (2004) method. Experiences from Norway over the last five years are also promising regarding evaluation of floor vibration perception using this method. However, attention should be given to floors with significantly lower damping properties and/or significantly higher (modal) masses. Damping properties or an alternative parameter taking a longer time interval of the vibrations into account should be considered.

## 1. Introduction

### 1.1. Objective

Constructions with wooden beams are very common in Norwegian single- and multifamily buildings both for vertical and horizontal partitions. For wooden joist floors, floor vibration properties have been an important topic for several decades and are the main focus of this paper. A lot of studies have been carried out in several countries, for example in [1–7]. Products, test methods, evaluation procedures and general understanding have improved very much in the last few decades. Static and vibrational performance have become crucial for serviceability of timber floors and often limits the design. However, constructors and designers want to increase the floor span width. To meet these challenges, reliable design methods are required and need to be in focus in many countries. With respect to standardization work, action has also been taken to revise Eurocode part 5 regarding floor vibration performance [8].

Since the end of the 1980s, research work and several studies have been carried out in Norway on floor vibration and serviceability of timber floors; examples include research work at the Norwegian Building Research Institute [9], thesis work by one of the author of this paper [11] and in the last decade research projects at SINTEF Building & Infrastructure. Except for [11], the results reported in [10–16] have only been published in Norwegian for the Norwegian Research Council and other project owners in the building sector. We recognize the need to analyse and compile results from the different projects. The aim of this article is therefore to summarize these results and present

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recommendations regarding methods and evaluation procedures. To substantiate the analysis, the paper will present results from numerous well-controlled measurements performed both in the laboratory and in situ.

### 1.2. Vibration properties

Timber floors need to meet requirements and expectations regarding structural performance, safety and serviceability in all aspects, for instance how people experience vibrations and springiness in timber floors where open-plan solutions with large span lengths are challenging. Due to their lightweight nature, timber floors are more sensitive to annoying vibrations induced by human activities than heavy concrete floors. The vibration performance of the floor structure itself is determined by the floor stiffness, mass and damping. The stiffness and mass properties of the floor determine the floor's natural frequencies. The damping affects the time it takes for an induced vibration to decay.

Measurements of dynamic and static properties of timber floors have been carried out in laboratories by many researchers. Results are available on parametric studies on floors and effects caused by natural frequencies, mode shape and damping ratio due to a number of parameters, both geometrical and product-related. The vibration performance of a floor changes as it is integrated into the structural system, adding parts like supplementary surface layers, partitions, fittings and fixtures. These added parts affect both floor mass and stiffness and consequently also the natural frequencies, mode shape and damping. Results presented in this article will contribute to the knowledge of this field.

## 2. Experimental investigations

### 2.1. Laboratory measurements

This paper presents results from four series of measurements performed in the laboratory from research projects listed below:

Lab-I: Norwegian Building Research Institute (NBI) measurements 1988
Lab-II: Thesis measurements 1999–2000
Lab-III: Web-joist project measurements 2003–2012
Lab-IV: Comfort Properties measurements 2007

Within each series, a number of objects have been investigated. Table 1 shows an overview of the different series including information regarding objects and parameters.

Both nationally and internationally, progress has been made on measurements and calculations within this topic. From this, new standards and recommendations regarding relevant parameters to characterize floor vibration properties have been developed. As a result, there have been some changes in measured parameters shown in Table 1. All measurement series presented in Table 1 include results of the fundamental frequency and the damping properties. In almost all cases, the static deflection from a point load has also been measured.

**Table 1**
Parameter overview, laboratory measurements of lightweight floor assemblies.

| Series | Total number of objects investigated | Extract in this paper | Measurement parameters[a] | Project reference | Ref. |
|---|---|---|---|---|---|
| Lab-I | 25 | Lab-I a to Lab-I f | $f_n$ (Hz), $\eta$ (%), $\Delta$ (mm) | NBI | [9] |
| Lab-II | 8 | Lab-II a, b and c | $f_n$ (Hz), $\eta$ (%), $h'_{max}$ (mm/s/Ns) | Thesis work, Homb | [11] |
| Lab-III | 2 | Lab-III an and b | $f_n$ (Hz), $\eta$ (%), $\Delta$ (mm), $h'_{max}$ (mm/s/Ns) | Master's thesis and NBI research work | [10,11,16] |
| Lab-IV | 17 | Lab-IV a to Lab-IV f | $f_n$ (Hz), $\eta$ (%), $\Delta$ (mm) | Comfort Properties research project | [16] |

[a] See Section 2.3 for explanation of the parameters.

**Table 2**
Parameter overview, field measurements of lightweight floor assemblies.

| Series | Total number of objects investigated | Extract in this paper | Measurement parameters[a] | Project reference | Ref. |
|---|---|---|---|---|---|
| Field-I | 4 | Field-I an and b | $f_n$ (Hz), $\eta$ (%), $h'_{max}$ (mm/s/Ns) | Thesis work, Homb | [11] |
| Field-II | 3 | Field-II an and b | $f_n$ (Hz), $\eta$ (%), $\Delta$ (mm) | Comfort properties and Modern Wood Joist research project | [16,17] |

[a] See Section 2.3 for explanation of the parameters.

### 2.2. Field measurements

This paper also includes field measurement results from the following studies and research projects:

Field-I: Thesis field measurements 2000–2002
Field-II: Web-joist field measurements 2005–2012

Within each series, a number of objects have been investigated. Table 2 shows an overview of the different series, including information regarding objects and parameters.

All measurement series presented in Table 2 include results related to the fundamental frequency and damping properties. Moreover, the static deflection and the maximum impulse velocity response have been measured in one series.

### 2.3. Measurement methods

#### 2.3.1. Point load deflection, Δ

The point load deflection of all objects is the measured deflection of the floor on the beam at the centre (weakest point) of the span width with a point load of 1.0 kN. It is also necessary to measure the deflection on the same beam at the support and on one or more neighbouring beams. The lateral positions of the beams have to be determined within an accuracy of approximately ± 5 mm. When the floor has a rather high transverse stiffness (perpendicular to the main beam direction), it is recommended to take measurements on at least five beams with a centre distance of 0.6 m. It is necessary to establish a reference system for the deflection measurements to ensure that the values are independent of the load at the different measurement positions. The principle and procedure are fully described in [18], chapter 2. Electronic deflection transducers have been used with a resolution of 0.01 mm.

The deflection of the beam construction is the average of a number of point load deflection results when values from the support/reference system have been taken into account.

#### 2.3.2. Fundamental frequency, $f_o$, and damping properties, η

Determination of the fundamental frequency and damping properties has been based on an impact source. An impact source is the most commonly used technique, since it is quick and easy. The convenience