Classification of human induced floor vibrations

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Summary

This paper summarizes results from vibration tests on floors. Classification of floors into five classes is attempted based on their vibration characteristics. Suggested criteria and limiting values are proposed. These values are based on tests carried out during the past years on different floors on site and in laboratory conditions. It was found that the point load deflection is among the best indicators of floor vibration quality of lightweight floors together with the natural frequency. It is further suggested that the deformation caused by the point load is divided into a local deflection mainly caused by soft toppings and floating floors and a global deflection of the main floor joists.

1. Introduction

The use of light-weight framing in housing is rapidly increasing. A complete building system needs also a floor system with good acoustic and vibration properties. Special design problems for light-weight floors, including steel, timber and light-weight concrete floors, are the sound insulation at low frequencies (under 100 Hz) and the floor vibrations due to walking.

Considering vibration performance, floors are usually grouped to low-frequency floors and high-frequency floors. Low-frequency floors are usually quite heavy floors and a person staying still may sense the resonance vibration due to another person walking. The high-frequency floors are usually light floors and a person staying still may sense the impacts due to separate steps of another person.

A third important group includes floating floors and raised floors. These types of superstructures are increasingly used because of impact sound insulation requirements and because of the flexibility of mounting the installations. There is not much experience of vibration behavior for these kinds of floors. The vibration or movements of objects, as clinking of glassware or leaf movement of plants, are typical for these kind of floors and it has been shown that such effects are highly dependant on the flexural stiffness of the top surface board. Local deflections are caused by soft floating floors and this needs to be limited to avoid such disturbances. On the positive side, floating floors with sufficient bending stiffness of the top layer may effectively distribute point loads to various floor joists and thus increasing the floor vibration performance. This phenomenon has been noted with some timber floors.

The human body is a very sensitive vibration meter. Even tiny vibrations can be annoying. Continuous vibration is felt more annoying than short-term, infrequent vibrations. If the vibrations are transferred from the neighboring apartment, the disturbance is more irritating than if the vibration source is in the same apartment. Also the type of room may have an effect on the disturbance, floor vibration in a summerhouse or in a detached house is not so irritating than in a block of flats.
Many different design criteria have been proposed for floors in residential buildings. The performance of lightweight floors is usually based on the deflection due to a 1 kN point load. Some of the deflection limits are span dependent [2] and some of them are frequency dependent [3]. The deflection criterion is given for the floor beams so that the deflection of sub-flooring is ignored. However, also the flooring board or an acoustic floating floor laid on the main floor may have a significant effect on the vibrations properties of the floor, especially on the movement of different objects such as plant leaves and clinging of glassware. The proposal in this paper is, that the deflection limit of high frequency floors is independent of the span and that there are two parts in this deflection: Local and global deflection. Local deflection is a deflection at a 600 mm distance caused by the floating floor or the top plate between floor joists and the global deflection is that of the main floor joist as the load is posed directly on it. Local deflections are mostly difficult to predict based on engineering calculations and it is recommended that these are determined based on tests. The bending stiffness of the floating floor top layer has a major impact on the local deflection. The global deflection on the other hand can be readily calculated.

For heavy floors the design criterion is based on the acceleration limit. Often the walking excitation is given by frequency-dependent harmonic force components [1]. The acceleration in resonance vibration is determined by the force component, which corresponds to the fundamental frequency of the floor. Also the standards for measuring the vibrations in buildings [4] and [5] give recommendations for the maximum accelerations in buildings. Also in this paper the design criterion for low frequency floors is based on the acceleration criterion.

The design codes give usually only one limit value for floors in residential buildings. Therefore it is often unclear for the designers, what does the limit value actually mean. How much better the floor actually is if we half the given limit value? This presentation proposes a five-class classification of floors in residential and office buildings. The classification forms a uniform basis for vibration performance. The producer can give different vibration classes for the product depending on the span or structural details of the construction. If the vibration classification of a certain product is not functioning, it is possible to move the product to a lower vibration class. Although the vibration design of floors is often quite inaccurate, the fact is that the better the target vibration class is, the better are the vibration properties of the floor. Therefore the vibration classification assists both designers and clients in making decisions regarding floor vibrations. Because the limits of the classes are in some cases based on a limited experience, it is quite obvious that there will be a need to check and update the limit values as more experience is gained.

2. Vibration classes

This presentation proposes a five-class classification of floors in residential and office buildings (Table 1). The class is composed of a capital letter. The letter represents the sense perception of a sitting person and the sense perception from vibrations of objects. The classification is material independent and it presumes that walking-induced vibrations are accepted as the basis of the design. Because the sensibility of vibrations is an individual feature, the descriptions given in Table 1 are very suggestive. Also the vibration of different objects depends much on the properties and on the position of the object.

Table 2 gives a proposal for the lowest permissible vibration classes. The vibration class shall always be agreed with the customer. A lower or higher class may be agreed for special products and special dimensions, if that is justified by earlier experience.


### Table 1. The vibration classification of floors based on the intensity of the vibration.

<table>
<thead>
<tr>
<th>Body perception</th>
<th>Vibration of articles</th>
</tr>
</thead>
<tbody>
<tr>
<td>A The vibrations are usually imperceptible.</td>
<td>The clinking of glassware and the leaf movements of a plant are usually imperceptible.</td>
</tr>
<tr>
<td>B The vibrations are barely perceptible.</td>
<td>The clinking of glassware is usually imperceptible and the leaf movements are barely perceptible.</td>
</tr>
</tbody>
</table>
| **C The vibrations are perceptible. Base class** | **The clinking of glassware is barely perceptible.**  
**The leaf movements perceptible** |
| D The vibrations are clearly perceptible. | The clinking of glassware the leaf movements are clearly perceptible. |
| E The vibrations are strongly perceptible. | The clinking of glassware and the leaf movements of a plant are strongly perceptible |

### Table 2. Proposal for vibration classes in office and residential buildings.

<table>
<thead>
<tr>
<th>Proposal</th>
<th>Description</th>
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</table>
| A        | Normal class for vibrations transferred from another apartment.  
Special class for vibrations inside one apartment. |
| B        | Lower class for vibrations transferred from another apartment.  
Higher class for vibrations inside one apartment |
| C, base class | **Normal class for vibrations inside one apartment.** |
| D        | Lower class for vibrations inside one apartment. For example attics and holiday cottages. |
| E        | Class without restrictions. |

### 3. Acceptance limits

Table 3 gives tentative parameter limit values for the corresponding vibration classes to be used in either design or in the testing of floors. The limit values are given for the following design quantities:

- The fundamental frequency $f_0$. The frequency $f_0 = 9$ Hz divides the floors into low-frequency and high-frequency floors.
- The root mean square for acceleration $a_{rms}$ [m/s$^2$] and for velocity $v_{rms}$ [mm/s] (during one second period).
- The peak vertical displacement $|u_{max}|$
- The peak vertical velocity $v_{max}$
- The global displacement of load bearing member $\delta_0$ [mm] due to 1 kN point load is used for high-frequency floors.
• The local displacement $\delta_1$ [mm] due to 1 kN point load, which is an additional part caused by soft toppings and floating floors. This particularly causes vibrations to articles and is therefore classed by the number on table 1. The total deformation limit of a point load is thus $\delta_0 + \delta_1$

The distance from the force to the reference point, from where the displacement is measured, is not less than 600 mm. The distance and the local displacement is measured from the top surface of the floor. The quantities given above are the mean values measured from three separate test samples and these include the strongest vibrations of each sample. The peak value is the maximum deviation from the mean value of the measured sample. The weight of the walking person shall be about 80 kg and the step velocity is 2 Hz. If the floor is low-frequency floor, also the step frequency proportional to the fundamental frequency of the floor shall be used. In this case the step frequency is determined from the fundamental frequency by dividing it by an integer, which results to step frequency less than 2 Hz, but is as close as possible 2 Hz. The distance of the vibration source to the measuring device is not less than 600 mm.

Table 3. Tentative acceptance limits for vibration classes.

<table>
<thead>
<tr>
<th>Class</th>
<th>Vibration values</th>
<th>Deflection values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$a_{rms}$ [m/s²]</td>
<td>$v_{max}$ [mm/s]</td>
</tr>
<tr>
<td>A</td>
<td>≤0.03</td>
<td>≤4</td>
</tr>
<tr>
<td>B</td>
<td>≤0.05</td>
<td>≤6</td>
</tr>
<tr>
<td>C</td>
<td>≤0.075</td>
<td>≤8</td>
</tr>
<tr>
<td>D</td>
<td>≤0.12</td>
<td>≤10</td>
</tr>
<tr>
<td>E</td>
<td>&gt;0.12</td>
<td>&gt;10</td>
</tr>
</tbody>
</table>

*a) Deflection of main load bearing floor joists  
*b) Additional deformation caused by floor tops (measured at a distance of 600 mm, fig. 1) which are either between member deformations of top plate or floating floor deformation.*

Figure 1. Examples of local deflection of floor surfaces.
4. Experimental verification of the acceptance limits

The test results gathered here are from different projects during the last 10 years and these include steel- and wood-framed floors with building boards or concrete slab top-flooring, hollow-core concrete slab floors, laminated veneer lumber (LVL) floors, floating floors and raised floors. More than half of the tests have been performed in laboratory circumstances and the rest in buildings under or right after construction.

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**Figure 2**: Deflection of 1 kN point load compared to acceptability. Includes all floors, with or without floating floor tops.

**Figure 3**: Local deflection on floating floors.
Figure 3 shows the effect of the floor top bending stiffness on the local deflection of the floating floor. Based on this limited experience, this relationship seems to be logarithmic. It may be noticed however that floor tops with higher bending stiffness’s result in more acceptable floors.

Figure 4: Acceleration compared to acceptability.

Figure 5: Dynamic deformation $u_{\text{max}}$ compared to acceptability.
Figure 6: Maximum velocity $V_{\text{max}}$ compared to acceptability.

The measurement of design quantities and the rating of intensity and acceptability were made using the same testing procedure. In rating by sense perceptions the observations were made both from body feeling and from vibrations of different objects. The observations were done by: a) body perception from a sitting position, b) clinking of a coffee cup with a spoon in the cup and on a saucer, c) leaf movements of a 30-40 cm high plant (planted inside a pot), d) rippling of water in a glass bowl, and e) chinking of a glass pane. The objects were set on a firm tripod support. The weight of the support was 20 kg. The glass pane was hung vertically to the portrait face by mirror hooks. The rating is based on a sitting observer’s body perception due to other person’s walking.

5. Conclusion

This paper describes an attempt to develop a classification system for the vibration behavior of floors. The results of floor tests from the past 10 years are gathered, these include timber, steel and concrete floors. Tentative limit values for various vibration values are given. It is recognized that these values may need adjustments as more experience is gathered. The benefit of a classification system is that the producers and the customers are more aware of the actual floor performance and on the target performance to be achieved. This floor class may be chosen on a case by case basis and not solely on a minimum requirement basis as the case is today. The classification has five quality levels and examples of class uses are: Class B for high quality apartments, class C for normal apartments, class D for single houses and class D or E for summer houses. It is recognized that the point load deflection is among the best indicators of floor quality for lightweight floors along with the natural frequency. Similar results have been found in recent studies carried out in Canada [2], [3].
6. References


Figure 7: Determination of floor properties by sense perception.