MEASUREMENTS OF LOW FREQUENCY IMPACT SOUND TRANSFER FUNCTIONS OF LIGHT WEIGHT TIMBER FLOORS, UTILIZING THE ISO RUBBER BALL

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Impact sound below 100 Hz is an important issue for light weight timber buildings. It is also well known that finite element model simulations are more beneficial in the low frequency range than in higher frequencies due to the longer wavelengths allowing the element meshes to be coarser. Utilizing transfer functions to describe impact sound would imply simplifications to correlate data stemming from measurements and low frequency finite element models. If the impact force is known, the simulations become easier since there would not be any need for the modelling of the impact mechanisms, just calculations of the transfer functions which are then combined with the force spectrum to give the resulting sound pressure. The impact ball has shown to be in close resemblance with a human's excitation in the low frequency range which makes it a suitable excitation device. However, when its force spectrum is needed, it may be hard in practice to achieve that during a regular measurement since the ball is not easily equipped with a force gauge. Here, two different methods are investigated. An investigation of the repeatability of the force spectrum of the rubber ball in the low frequency range for floors having different mobilities is made. To enable this, an equipment for field measurements of impact force spectrum and potentially point mobilities using an ISO ball, is designed, manufactured and evaluated. Impact force measurements are made on lightweight timber as well as concrete floors, with different properties for comparisons. Within the lowest frequencies it is potentially possible to use one given force spectrum from the ISO ball together with impact sound measurements for the creation of impact force to sound transfer functions on different floors.

Keywords: impact sound, low frequency, ball

1. Introduction

Due to an increased awareness in the society of sustainability, there is also an interest in increasing construction of sustainable multi storey buildings. Timber is a renewable natural material that fits many of the requirements and ambitions set by the community, as well as of residential customers.

One significant difference compared to concrete buildings is the impact sound transmission; common disturbances stem from feet impact from neighbouring apartments. In concrete buildings, the most disturbing impact sounds tend to be in the traditional range for measurements of building acoustics, i.e. approximately within 100 Hz – 3500 Hz. Timber has significantly different mechanical properties than concrete. Strength per unit weight is normally noteworthy higher for typical timber construction materials (Norwegian spruce for instance). On the other hand, the density is lower for timber than for concrete. Designing based on only structural strength will give significantly lighter timber
floors than associated concrete floors. Multi-storey timber buildings have, in general, low impact sound transmission in high frequencies. On the other hand, the impact sound in low frequencies are more significant. The range 20 Hz – 100 Hz has shown to be important for the perception and satisfaction of impact sound in timber buildings [1]. Most of this range is below the range covered by modern building regulations and measurement standards i.e. normally 100 Hz -3150 Hz [2, 3] and 50 Hz - 3150 Hz in Sweden, which is the country having requirements with the lowest frequency limit [4].

Impact sound measurements are predominantly made with the ISO tapping machine [2, 5]. One problem with the tapping machine is that its force spectrum differs much from a real human foot’s excitation in the low frequencies. The force is significantly lower in the lowest frequencies, introducing a risk of errors due to non-linearities and also due to poor signal to noise ratios [6]. The ISO rubber ball [2, 5] has shown to be a suitable measurement device for excitation of impact sound in low frequencies [6] and it represents good correlation to humans’ perception [1, 7].

When it comes to development of new building products, the building industry would potentially also be benefited by optimization using simulations before prototypes are tested and built, as in other industries. One obstacle is that simulation of the tapping machine or other impacts are difficult to make [8]. Simulations of transfer functions are well supported in many Finite Element (FE) software and is simpler compared to simulations of impact mechanics of the ISO tapping machine interacting with floor surfaces [8]. In order to achieve transfer function measurements and correlations, the force spectrum is needed to be measured. FEM is well used in statics and in the modal range. It would then be natural to try to use FE representations in the low frequencies for timber buildings.

Here, the aim is to find a method for measuring / achieving the excitation’s force spectrum of the ISO rubber ball. First a prototype equipment (test rig) for field measurements of impact force spectra and potentially point mobilities with ISO ball, is used in the force spectrum measurements and evaluated. Second an investigation is made on how stable the force spectrum of the rubber ball is, in the low frequency range, for floors having different motilities.

2. Measurement objects

2.1 Floors

Two office buildings on the university campus in Växjö, Sweden were chosen for the experimental work. The selected M- and N-buildings have different timber-joist floor constructions. Ten measurement points were randomly selected on each of the selected floors. In the M-building the measurements were made on the second floor in the north corridor. The selected timber-joist floor in the M-building has solid spruce joists (220 mm deep, 45 mm wide) at centre to centre distances ranging from 90 to 180 mm. There are compressed mineral wool between the joists. The 22 mm particle board above the joists are glued and screwed to the joists. On top of the joists, the floor comprises lino on a 13 mm gypsum board. At the bottom of the joists floor there are 70 mm x 28 mm distance bars fixed to a 13 mm gypsum board. Below this there is a 568 mm deep void with a suspended ceiling formed from a 10 mm mineral wool board. The non-load bearing walls are connected to the gypsum board that is attached to the underside of the joists. The joist floors are resting on steel beams which are likely to affect the stiffness at measurement points close or above these.

The timber-joist floor in the selected area in the N-building has a thickness of 438 mm. It consists of Laminated Veneer Lumber (LVL), a 31 mm horizontal upper board, I-beams (405 mm deep) with 587 mm divisions. Between the I-beams there are 220 mm x 565 mm mineral wool. On the joist floor, the floor comprises lino on double 12.5 mm gypsum boards on 25 mm mineral wool. Below, the joists floor is fixed to a 13 mm gypsum board, below which is a 400–800 mm deep void with a suspended ceiling formed from two 13 mm gypsum boards. The non-load bearing walls below the floor are moveable and stop at suspended ceilings. The joist floors are resting on glue lam beams which are connected to wood wall studs for the outer walls. The measurements in the N-building were made on the second floor, in the east corridor.
For comparison, measurements were also made on the concrete floor in the lab-hall in the M-building. Details of how thick the floor is, is not exactly known, but its point mobility is measured so its dynamic properties are identified. For the concrete floor three measurement points were judged to be enough since the floor is more homogenous than the joist structure of the timber floors.

Characteristic for both the M- and N-building is that they have light timber floors. By measuring on these floors and on the concrete floor, a range in extremes from light to heavy floors are covered. Measured point mobility curves identify the dynamic properties of the different floors.

2.2 Floor coverings

Additional measurements were made in order to analyse the influence on force spectrum measurements due to potential and common coverings of floor structures. The following coverings were used:

1. A 12 mm thick, MDF board (area 64 x 39 cm width and length, 640 kg/m³) above different amounts of layers of 3 mm expanded polystyrene (XPS), brand Balinek with a surface weight of 35 kg/m².
2. A sample 400 x 300 mm “Wall-to-wall carpet”, 12 mm thick “twisted velour”, pile weight 1.37 kg/m².
3. A sample 400 x 300 mm “Wall-to-wall carpet”, 15 mm thick “rug math”, pile weight 0.925 kg/m².

The coverings were put directly on measurement point number three on the concrete floor in the M-building.

3. Method

3.1 Point mobility measurements

The point mobilities of the different floors were measured with an impact hammer and an accelerometer. The excitations were made close to the accelerometer on the floor. At least five separate excitations were made for each of the measurements.

3.2 Force spectrum measurements and the test rig.

Force spectrum measurements of the impact ball excitations were made with our Ball Impact Measurement Rig (BIM rig). The aims of the rig is to:

1. Be able to measure the force at impact of the ISO ball.
2. Enable high repeatability in the dropping procedure, i.e. correct height and vertical straightness of the drop.
3. Measure point accelerance at the impact point with addition / activation of an accelerometer alongside the force gauge.
4. To be suitable in operation and transportation for field measurements.

The prototype BIM rig, shown in Figure 1, consists of two main parts:

1. The floor-standing tripod together with the ball guide part. Having three contact points disables play between the rig and the floor (as may be the case with four contact points). The bottom plate is made of 20 mm aluminium with a distance of 294 mm between the contact points to the floor. The contact points consist of rubber fleets. The ball guide part is a ring that has the same diameter as the impact ball and is placed 1.00 m from the drop plate. The total weight of this part is approximately 3.8 kg.
2. The drop plate with a force gauge and plastic hammer intersection to the floor. This part is vertically disconnected from the other part with a ball bearing translation guide for the force part but also three smaller bearing guided pins. The drop plate is made of aluminium and is approximately 20 mm thick and it has a diameter of 152 mm. The force measurement gauge is a PCB 208C04; it is connected to the plate via a stainless steel pin (diameter 20 mm height 38 mm), which is connected to a nylon plastic hammer part (diameter 31 mm, height 23 mm,
vaguely rounded intersection surface to the floor). These parts have a weight of approximately 1.3 kg.

Thus, the BIM rig has a total weight of approximately 5 kg. The measurements of the force spectra are made on the chosen floors with the impact ball dropped from 1.00 m, using the test rig and its force gauge. All the presented standard deviations are from average values of five ball excitations, i.e. the average value is one sample used in the standard deviation calculations. The measurements are made with 2.0 seconds acquisition time, exponential windowing and 0.5 Hz spectral resolution.

Figure 1. Photos showing the Ball Impact Measurement rig. The right photo shows the ball in its maximum height position from where it is dropped. The crosses on the floor show three of the randomly selected measurement points in the N-building.

4. Results

4.1 Floor and floor coverings point mobilities

Floor impact point mobilities from 10 Hz to 400 Hz are presented in Figure 2 for the different floors. The M- and N-buildings’ timber floors have the highest point mobilities with values up to -50 dB for the M-building and up to -45 dB for the N-building. The concrete floor is significantly stiffer and heavier with a maximum point mobility approximately up to -88 dB in the range from 30 to 70 Hz.
Figure 2. Diagram of the point mobilities at the different floors at one point (the average of five excitations).

4.2 Force spectrum

Force spectra for the different excitation points in the M- and N-buildings are presented in Figure 3. Force spectra for the concrete floor and the different coverings of the concrete floor are presented in Figure 4. In Figure 5 the average force spectra of the different floors are plotted together. The second diagram in Figure 5 shows the maximum and minimum span for all force spectra measured, including the floor coverings test. The diagrams show that up to 50 Hz, the force spectra for all measurements, have less than 1 dB deviations. From approximately 60 Hz the difference due to different floor and coverings are increasing rapidly. Figure 6 shows the standard deviation compared to the average spectrum’s amplitude, for each floor. The purpose is to show the variations compared to the amplitudes. All presented standard deviations are calculated from the average values for each floor point (five ball excitations each).

Figure 3. Averages and standard deviations for the force spectra of the ten excitation points in the M- (left diagram) and in the N-building (right diagram).
Figure 4. Force spectrum of the concrete floor in the M-building (three measurement points) and the average values of tests of different coverings made on the same concrete floor.

Figure 5. The left diagram shows the average force spectrum for the different floors tested. The right one shows the minimum and maximum forces taken from all measurements of the floors and the coverings (average values), together with the span, i.e. maximum minus minimum.
5. Conclusions

The point mobility measurements show a wide range from the light timber floors to the concrete floor. Although the range is significant, up to 40 dB difference up to 50 Hz, the differences in the force spectra are less than 1 dB in this range. The range from 20 to 50 Hz is important for the perception of impact sound [1]. It shows that achieving transfer functions from impact force to sound in this range could be easily achieved without really measuring the impact force when dropping the impact ball from 1.00 meter height. The force spectrum from a ball that is calibrated / measured could be used in field measurements. By just measuring the impact sound (and potentially vibrations) in neighbouring rooms, reliable transfer functions from force to sound can be achieved in the range up to 50 Hz with good precision. Above that frequency range, the impact force must be measured, which is the purpose with the here used Ball Impact Measurement rig. The test rig is a prototype and it has shown a good potential for achieving force spectra in field test measurements. The test rig is light enough (approximately 5 kg) for being suitable for field test situations. The test could potentially also be used for measuring point mobilities. Timber buildings built according to the Eurocode 5 standard have static deflection requirements, in its National Annexes (NA) for a 1 kN point load. Indicative measurements of low frequency stiffness due to point load may be achieved in the same measurements but have to be measured and evaluated further. An obstacle compared to for instance the ISO tapping machine is the increased complexity to measure in another room at the same time as the receiving room with cabling etc. However, in the age of IOT (Internet of Things) where all measurement equipment are connected, it would be possible to make the ball drops independently without synchronisation cable, just synchronisation with time and registration mark at trigger levels, and later on merged to form FRFs.

The test rig has to be evaluated further. For instance, in its current state it has rubber feet which may give resonances in low frequencies at the excitations, which may affect the quality of the measurements.
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REFERENCES

5 ISO 10140-5. Acoustics – Laboratory measurements of sound insulation of building elements. Part 5: Requirements for test facilities and equipment.
6 Olsson J., and Linderholt A. Low frequency force to sound pressure transfer function measurements using a modified tapping machine on a light weight wooden joist floor, Proceedings of the World Conference on Timber Engineering, Vienna, Austria (WCTE), (2016).