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ACOUSTICAL MEASUREMENTS AT LIMNOLOGEN, VÄXJÖ, SWEDEN

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Introduction

The industry of making large wooden houses is in an emerging state and is today supported by governmental efforts. The development of new building techniques for timber framed houses is thereby developed with the hope of a new large market. Building a high-rise modern wooden house implies many technical challenges as one have to combine modern architecture with comfort, health and safety criteria's. The sound insulation of these buildings is definitely one of them. It has been shown that it takes a lot of engineering efforts to combine stability with good sound insulation.

The building code in Sweden is pointing to the Swedish classification standard for sound insulation. There is one class for the basic requirements and two classes for achieving good and excellent sound comfort respectively. Considering that new building projects are a large investment it makes sense to consider that the owner may require a reasonably good sound insulation class, thereby cutting down the number of complaints that will emerge for sound related problems.

Limnologen is a building that is a part of the governmental promotion program for building with timber. It is also a part of a local authority programme for building a wooden city near Växjö University campus. The building has been the object of several studies both for its technique and other criteria's, e.g. economies. This is mostly due to CBBT - Centre for building and living with wood, collaboration between the local authorities, the university, the local industry and SP - Swedish institute for research. This project is directly sponsored by CBBT.

This work is based on measurements in-situ.

Measurements performed

A series of different acoustical and vibrationnal measurements has been performed to study the sound transmission behaviour for Limnologen.

- Impact sound level
- Sound reduction index
- Examination of the vibration pattern of the floor structure
- An investigation of the sound propagation through a real wood cross junction.

All the results and measurements sets up are presented in the following papers.

Measurements and Pictures diary

All the measurements have been performed during nights and weekends, in December 2007 and January 2008, to avoid background noise and other disturbances which will interfere with the measurements results.

- <u>Vibration pattern of the floor</u>

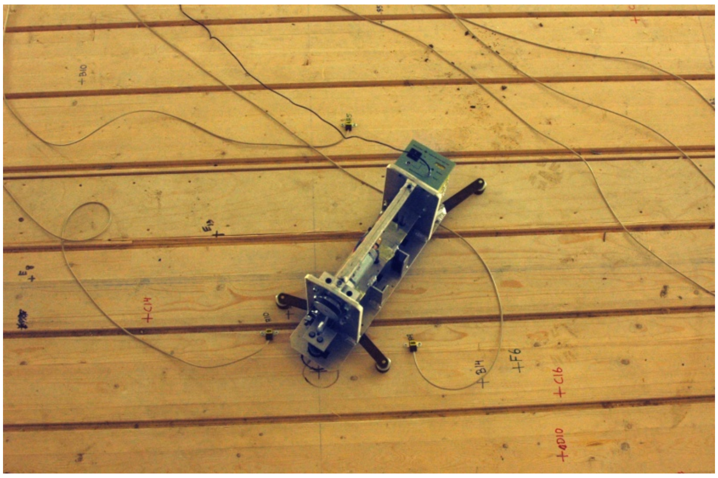

Figure 1: Hammer without case

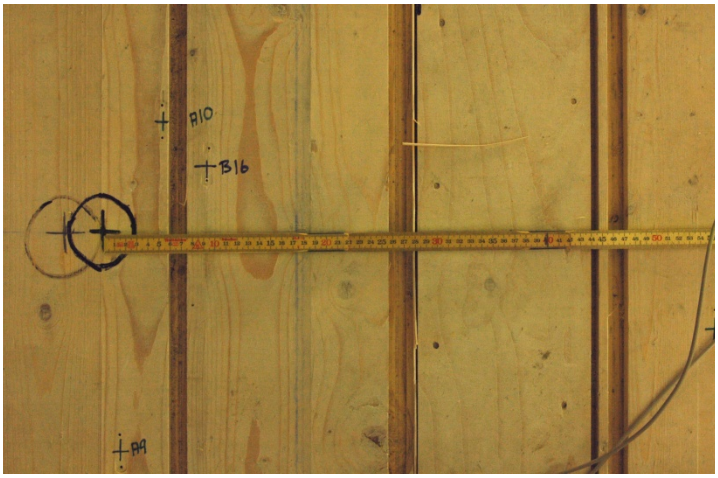

Figure 2: Distances between hammer impact and accelerometers

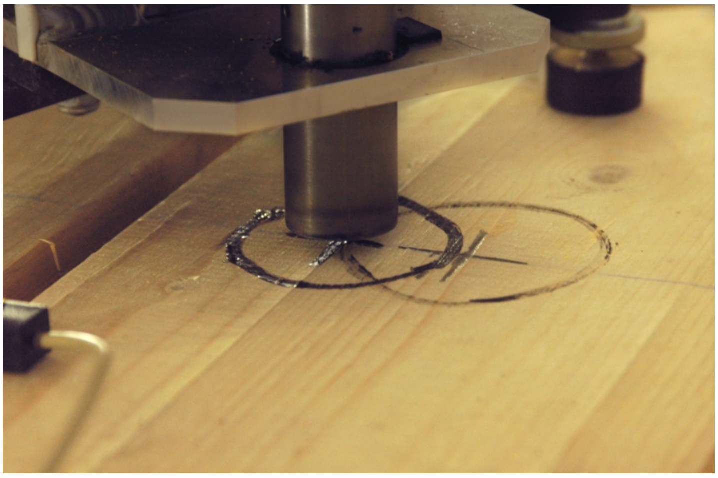

Figure 3: Hammer impact

- <u>Measurementrs of the vibration through the cross junction</u>

Figure 4: Hammer in front of the measured wall with 16 accelerometers

Figure 5: Accelerometers fixe on the ceiling

Figure 6: Accelerometers fixe on the wall

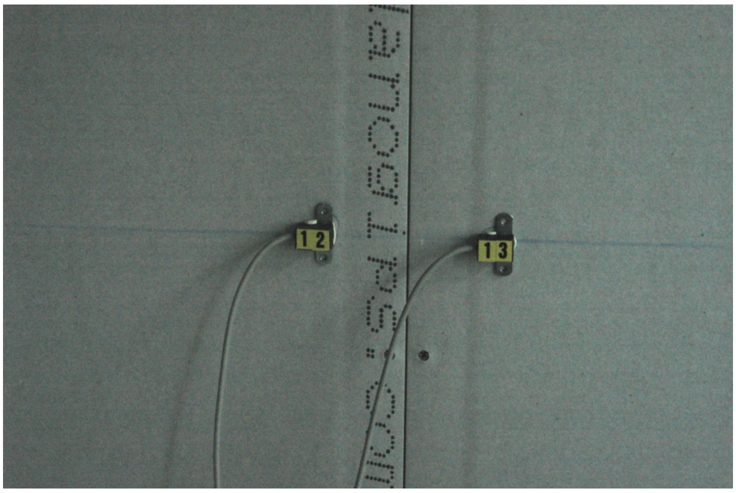

Figure 7: Accelerometers near a beam on the wall

- And the authors at work....

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Sound transmission through a complete wood cross junction in a light-weight building

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ABSTRACT

Lightweight constructions of timber material have a number of advantages; it is cost effective and demands relatively short production duration. One of the main drawbacks of lightweight structures is related to sound transmission. The differences in weight, density and repartition they bring have repercussions on how the sound propagates in the rooms and in the structures themselves. Sound transmission becomes an increasing nuisance. To be able to reduce the sound transmission, a better understanding of how the sound propagates through a real wood cross junction is needed. This work is based on measurements in-situ. A series of measurements using accelerometers have been performed on a wooden frame building in Sweden. The multi-family house has seven storeys.

1 INTRODUCTION

For high-rise wooden buildings the largest acoustical challenge is to determine and reduce sound transmission, especially flanking transmission. This work takes place in a Swedish wooden construction project: Välle Broar project in Växjö, Sweden. Välle Broar is a part of the city where wood buildings are built with modern techniques. The project *Limnologen* is a part of it. The aim is to develop the industrial building technique for houses built with wood since wood is thought to be an environmentally friendly material. The *Limnologen* buildings are the highest buildings in Sweden constructed with a load-bearing framework made of wood, see Fig.1.

The ground floor is cast in concrete, but the rest of the bearing framework; seven floors, is entirely made of wood. The side of the building that is facing northeast has a glue-laminated timber facade (Fig.2) and the opposite side is covered with plaster (Fig.3). Only the topmost story's facade is made entirely of glue-laminated timber.

The floor structure stretches between the exterior walls on the two long sides of the building. In apartments that are continuous between these two sides the floor structures are supported midways by a bearing wall or a beam.

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Figure 1: Wooden building Limnologen

Figure 2: Facade facing southwest

Figure 3: Facade facing northeast

To solve noise problems the ceiling is not in contact with the floor structure. The individual apartments are separated by an air gap, but at several points there are connections of the floor structures of two neighboring apartments to transfer the horizontal forces in the building.

2 MEASUREMENTS

2.1 Wood building

For the transmission of vibrations through the house four building parts are important: The floor structure, the ceiling, the apartment separating wall and the inner wall.

Floor

The floor structure is the upper part of the floor element, as shown in figure 5.3. The top is made out of three layers of massive timber. The middle layer is rotated 90 degrees with respect to the two outer layers. Underneath these layers wooden T-beams are positioned. They are made of glue laminated timber and stiffen the floor structure in its longitudinal direction. Between the beams there is an insulation layer. The floor structures are manufactured with a width of 1.2 meters and in various lengths.

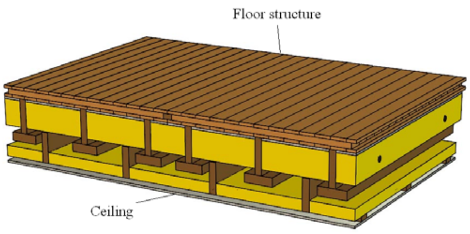

Figure 4: floor element, floor structure and ceiling, made by Martinsons Byggsystem AB.

Apartment separating walls

In order to reduce the sound transmission between different apartments a special kind of wall is used. The construction of the apartment separating wall is formed to reach the demands of sound insulation, class B.

The apartment separating wall is a part of the vertical bearing frame composed by studs with a center distance of 600 mm. A board is connected to the studs on top of which battens are fastened with a center distance of 450 mm. The outer parts are two gypsum boards. Between the beams, both studs and battens, there is wood fiber insulation. The wall is composed of two of those layers separated by a 20 mm air gap. This air gap prevents mechanical vibrations from transferring directly between the walls.

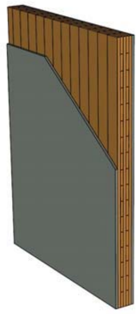

Figure 5: An inner wall containing five layers of massive wood and one gypsum board

Ceiling

The ceiling is the lower part of the floor element, shown in figure 4. It is made of massive wood studs and battens which are orthogonal to each other. Two 13 mm gypsum boards are fastened on the battens. The studs and battens make the structure stiffer in both directions. Between the studs, some wood fiber insulation is placed.

2.2 Measurements set up

In order to measure sound propagation, direct (1) and flanking transmission (2), through a wood cross junction (see Fig.6); two types of instruments are needed: A tapping machine and accelerometers.
The test structure was excited by a tapping machine, delivering reproducible impacts. One hammer was used. An array of 16 accelerometers registered the response. The accelerometers were re-located to determine the vibration pattern, at 4 different positions on the floor/wall/ceiling in each room.

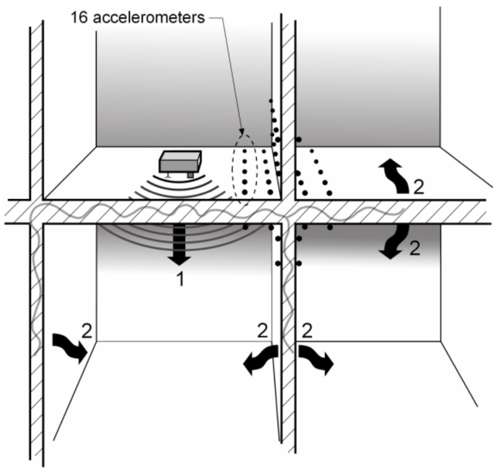

Figure 6: Measurements set up

3 WAVE PROPAGATION

3.1 Bending waves

According to [2] the wave equation for a bending wave propagating along the *x*-axis has the following generic expression for the displacement η in the *z*-direction (perpendicular to the surface):

$$\eta(x,t) = [\eta_{+} \exp(-ik_B x) + \eta_{-} \exp(ik_B x) + \eta_{n-} \exp(-k_B x) + \eta_{n+} \exp(k_B x)] \cdot \exp(i\omega t) \qquad (1)$$

where η_{+}, η_{-}, η_{n-}, η_{n+} are constants. While first and second terms within the brackets refer to the propagation of a sinusoidal bending wave, the third and fourth terms represents nearfields vibration waves that decay away exponentially in the positive and negative *x*-directions. This latter type of wave will be considered here, since the excitation consists of short impacts, not sustained sinusoidal waves.

4 RESULTS

4.1 Excitation room

The configuration of the room in which the tapping machine is placed is an important criterion to be taken into account for the understanding of the measurements results. The actual setup for the floor measurements is illustrated on Fig.7, with the wall junction under study on the top, and the position of the underlying T-beams indicated as vertical lines on the picture. The coordinates along the *x*-axis are indicated at the bottom, in meters. The tapping machine takes place roughly in the middle of the room, and is represented by a red sign. The path of the vibration wave, from the source to the wall is illustrated by straight lines putting in evidence what the measured data correspond to. As the sound waves propagate into the floor, through the junction and into the walls, they will cross internal beams, which will affect them. Also, the finite dimensions of the room had to be taken into account. The levels measured along the wall under study were affected by reflections along the remaining walls of the room. One reflection against the wall (affecting sensor number 13 in that case) is illustrated on the left side, with a dashed line. The accelerometers were disposed in such a way as to measure on each side of each beam and in-between almost every pair of successive beams. The 16 accelerometers were fixed on the floor at distances of 5 cm and 50 cm from the wall respectively. Then, they were fixed against the wall, first at a distance of 10 cm, then 1 m from the floor.

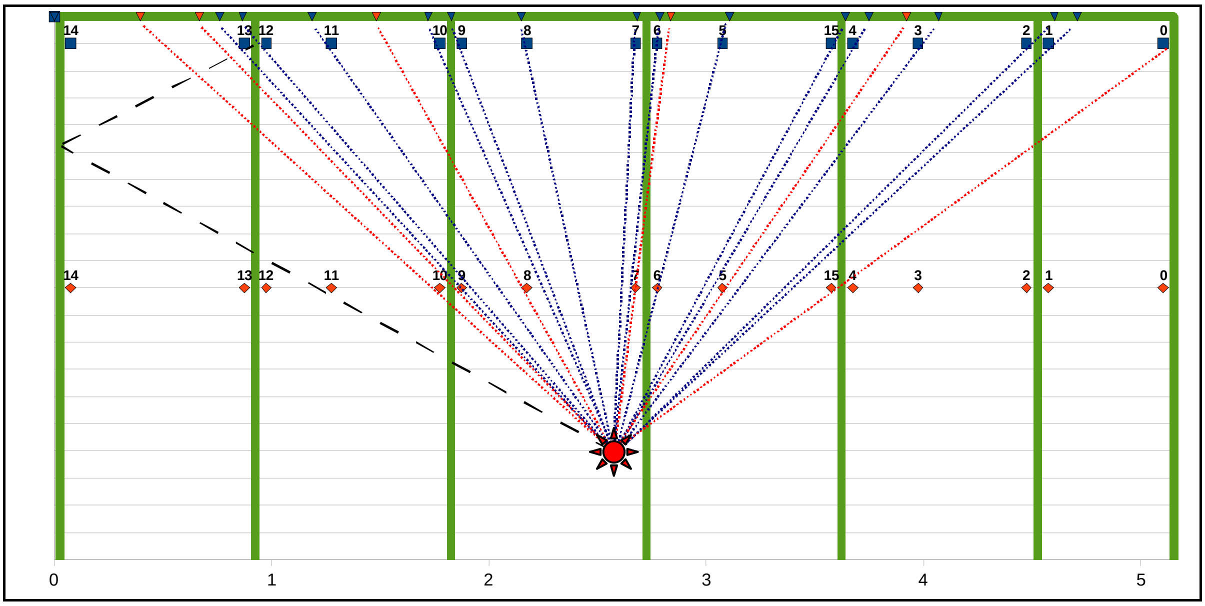

Figure 7: Placement of both lines of accelerometers in the room

The accelerometer placement was reproduced identically in the adjacent room. This means that each accelerometer had its counterpart placed symmetrically on the other side of the wall. Finally, the device placement of both rooms was mirrored in two room's one floor underneath, however with accelerometers attached to the ceiling instead of the floor, and at 10 cm and 1 m under the ceiling for the wall measurements. Thereby, a total of 16 measurements sets were collected, each of them consisting of 16 accelerometer channels of data over a period of 10 seconds. The acquisition system samples the data at a frequency of 9500 Hz.

4.2 Measures in the excitation room

The measurement data obtained in the room where the tapping machine was placed provides crucial information about the nature of the impact wave that propagates through the structure. Several parameters influences the result obtained.

- The distance to the source: the impact magnitude is expected to show an exponential decay over the distance. This assumption will be verified and taken into account.
- The angle of incidence: since the floor is constituted of several superimposed layers of timber wood and crossing each other at right angles, one would expect the propagation characteristics to be angle-dependent.
- The reflections on walls: the measurement delivered by an accelerometer placed close to a side wall will be altered due to vibration waves being reflected on the wall nearby, and superimposed to the incident wave. The closer the wall, the shorter the delay between the direct and the indirect waves, and the smaller its attenuation.

The maximal magnitude of the acceleration is plotted as a function of the distance to the impact source (Fig.8). The distances range from about 30 cm for the accelerometer at the middle of the first row to about 2.63 m at the extremities of the second row. The curve is traced using a semi-log scale. As expected, the measured points align along a straight line. However, only half of the points, corresponding to the accelerometers in the middle of the room, obey to this trend. For the remaining points, the opposite trend can be observed, namely the magnitude getting larger as the distance to the source increases. The reason is that the reflections on the wall get more important as the distance to them decreases. The indirect impact wave is superimposed to the direct wave and their magnitudes either sum up if they are in phase, or subtract if they are out of phase. Eventually, when the distance gets even larger, the delay between the peaks would be such that they no longer merge into one bigger peak. Calculations will show later in this section whether this hypothetical case is likely to happen.

By picking two points from the line on the picture, one can define the exponential decay rate k_B. This parameter is found to be equal to 0.433 m^{-1}. This corresponds to halving the magnitude after a distance of 1.6 m.

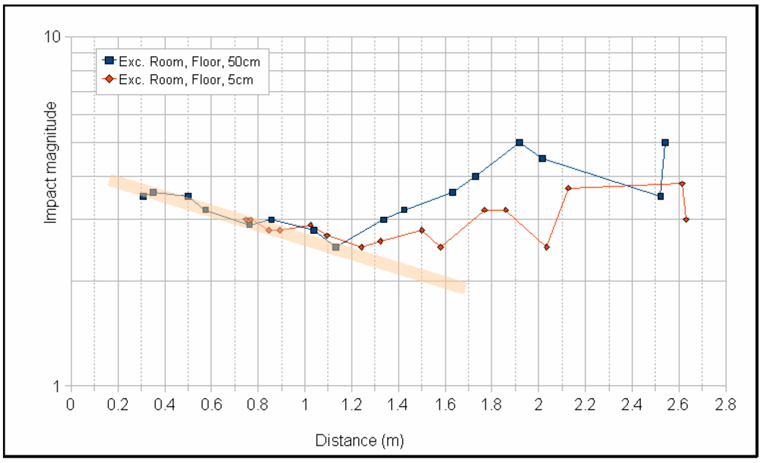

Figure 8: Impact acceleration magnitude as a function of the distance to the source.

Since the exponential decay rate of the acceleration peak magnitude as a function of the distance is known, the peak magnitude at a distance of 1 m can be determined from the measurements. This normalized acceleration magnitude is plotted as a function of the incidence angle θ between the propagation direction and the wall. The result is represented on the Fig.9.

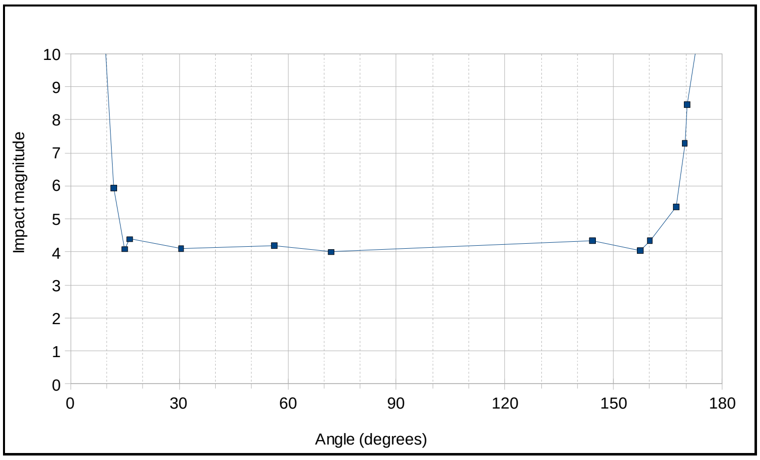

Figure 9: Normalized impact acceleration magnitude as a function of the incidence angle.

A similar approach can be used to determine the speed at which the impact acceleration wave propagates. Since the accelerations resulting from the 16 sensors were recorded simultaneously, one can determine the time at which the peak of the acceleration wave reaches each accelerometer. The plot of the time delay as a function of the distance to the source results in a straight line, as it can be seen on Fig.10. The slope of this line is the speed of propagation of the impact wave in the floor, which is found to be equal to 674 m/s.

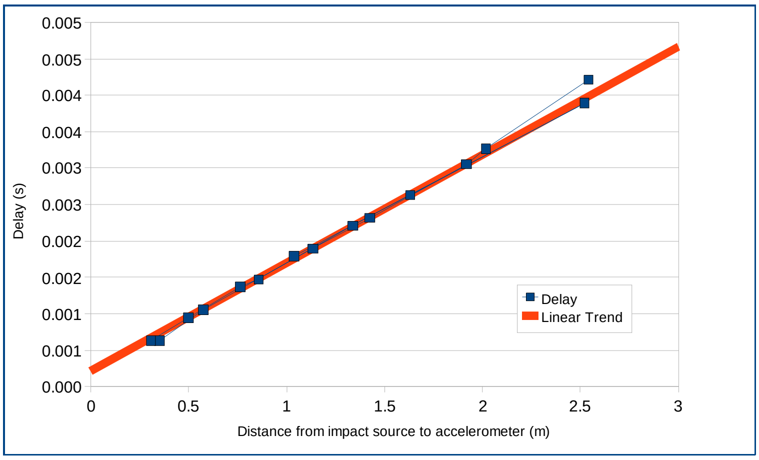

Figure 10: Time delay of the impact acceleration as a function of the distance to the source.

The experiment data shows that the average length of an impact peak is about 40 ms when considering only the direct wave path, *i.e.* for a sensor that is not located close to walls. It can be considered, as a rule of thumb, that peak superimposition can be clearly detected when the time delay between the direct impact wave and the first indirect wave is at least half of the peak length, which is 20 ms. According to the propagation speed calculated previously, this would mean a wave path length difference of around 13 m. Therefore, a condition for clearly separating superimposed peaks would be to consider only sensors placed at a minimum distance of 6.5 m from any wall (the wave has to travel twice the distance when it bounces on a wall and returns to the origin point), which is not an option in our configuration. As a consequence, using a large number of sensors and analyzing statistically the data they deliver is probably the safest way to extract relevant information.

Since the impact wave propagation speed has been calculated and it has been verified that the data recorded by the accelerometers placed in the middle of the room do not suffer from unwanted reflection superimposing to the direct wave, the data delivered by the sensors can be used to extrapolate the acceleration magnitude that the impact wave is supposed to have when it reaches the wall. The equation (2) is used for that purpose. For each sensor, the corresponding position along the wall is represented on the figure 7, assuming the wave propagates along a straight line from the tapping machine to the wall, through the different sensors.

$$a_{i,wall} = a_{i,acc} \cdot \exp(-k_B \cdot d_{i,wall\text{-}acc}) \qquad (2)$$

where $a_{i,acc}$ is the acceleration measured by the ith sensor, $a_{i,wall}$ is the corresponding acceleration value along the wall, and $d_{i,wall\text{-}acc}$ is the distance from the sensor to the wall, when following the vibration wave path. Finally, k is the exponential decay factor determined earlier.

The figure 11 represents the extrapolated acceleration peak magnitudes along the wall. Notice that the number of points on the curve is lower than the total number of accelerometers, since only the ones in the center of the room can be used to measure direct vibrations waves propagating from the source to the wall.

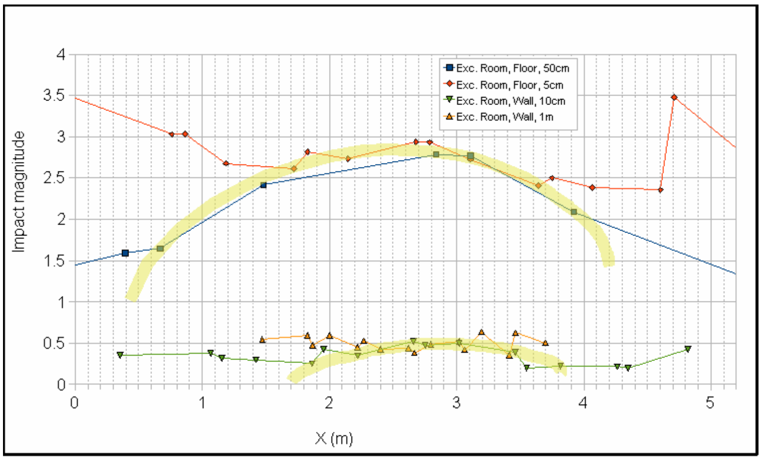

Figure 11: Magnitude of the impact acceleration in the floor, along the wall, as a function of the X-coordinates and corresponding acceleration recorded on the wall in the same room.

4.3 Transmission ratio of the junction

The propagation characteristics of the junction are considered for all different wave paths: from the wall of the excitation room to the wall in the same room, and to the walls and floors or ceiling in the 3 adjacent rooms. Since the acceleration is recorded at a position that does not lie exactly along the wall, the value actually measured has also been extrapolated to fit the value that it should have along the wall. This time, though, the extrapolated data will be slightly higher than the measured one, since the wall is closer to the source, compared to the sensors, hence the sign inversion in the exponential term in equation (3):

$$a_{i,wall} = a_{i,acc} \cdot \exp\,(k_B \cdot d_{i,acc\text{-}wall}) \qquad (3)$$

where $d_{i,\ acc\text{-}wall}$ is the distance from the wall to the sensor.

In order to determine the transmission coefficient, the ratio of the peak magnitude after the junction over its value before the junction, is calculated as a function of the position along the wall.

The results are plotted first for the measurements done on the walls. The coefficient plotted represents the ratio of acceleration magnitudes in the considered room over the magnitude recorded on the floor of the excitation room.

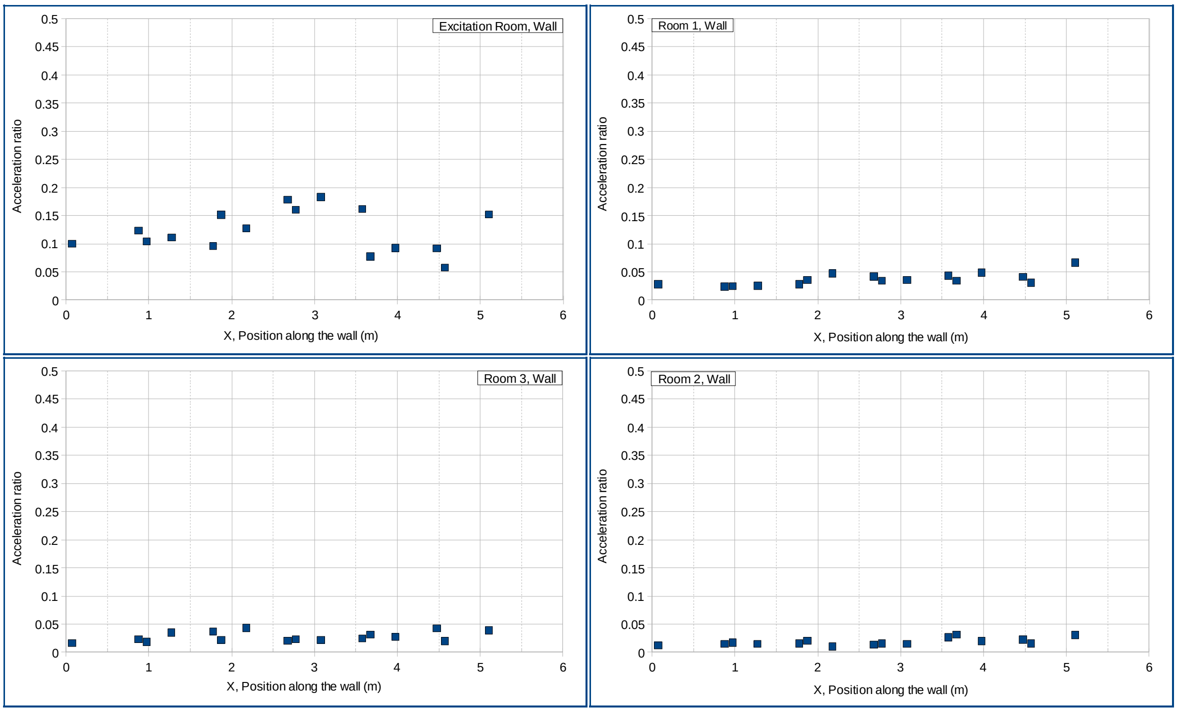

Figure 12: Transmission coefficient of the junction for a impact wave path propagating from the floor in the excitation room to the wall in excitation room (upper left), in room 1 (upper right), in room 2 (lower right) and in room 3 (lower left).The coefficient is defined here as the ratio of the acceleration before and after the junction, and is plotted as a function of the X-coordinates along the junction.

It can be observed that the impact wave is transmitted from the floor to the wall in a significant way only in the excitation room. In that particular room, the magnitude recorded is four times higher than in the adjacent room, or in the rooms underneath. Also, it must be noticed that the transmission ratio is slightly larger on the left side of the room. This can make sense when we consider that the wall on the left side of the wall is a stronger and thicker external wall, thus probably reflecting a high part of the vibrations.

Then, the results for the measurements made on the floor of room 1 and at the ceiling of rooms 1 and 2 are presented.

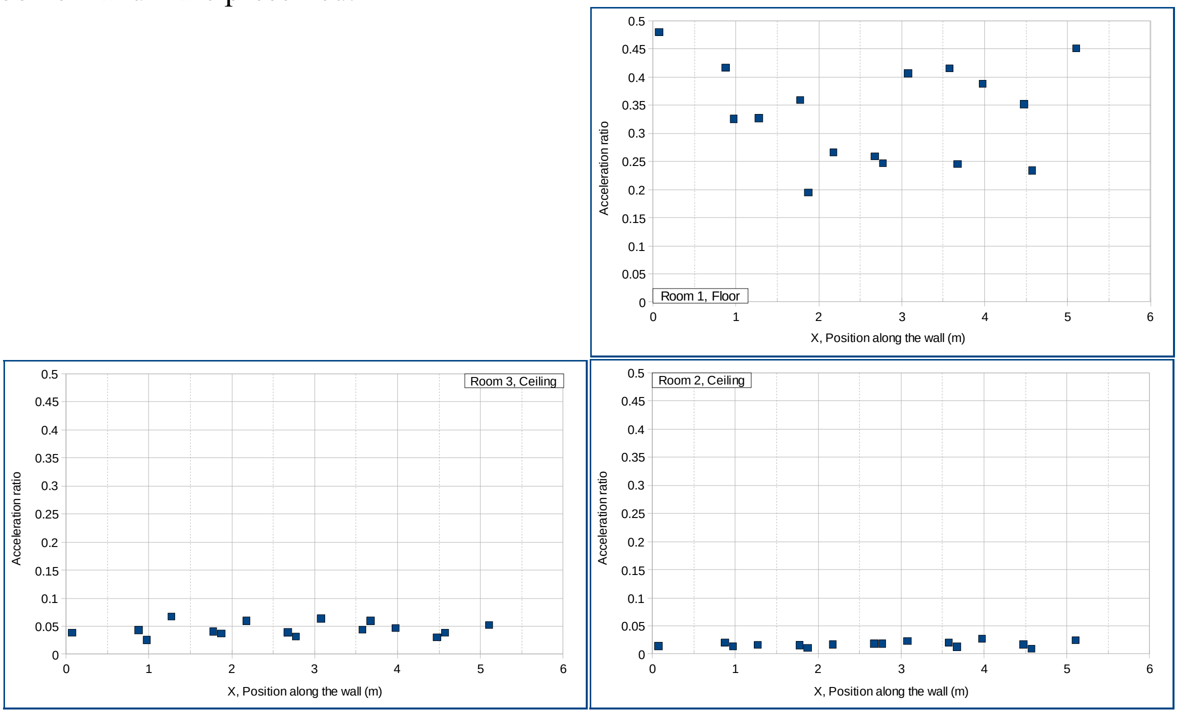

Figure 13: Transmission coefficient of the junction for a impact wave path propagating from the floor in the excitation room to the floor in room 1 (upper right corner) and to the ceiling, in room 2 (lower right) and in room 3 (lower left).The coefficient is defined here as the ratio of the acceleration before and after the junction, and is plotted as a function of the X-coordinates along the junction.

In contrary to the wall vibration measurements, we can distinguish here a rather high transmission ratio from the excitation room to the room 1. In addition, both left and right extremities show much higher values, which can be explained by the presence of the walls. Also, the transmission from the excitation room to the room 3, underneath it, is rather high. However, this can not be attributed exclusively to the junction beam, but rather to the direct transmission through the floor itself.

5 CONCLUSION

For the first time to our knowledge, extensive measurements of vibration propagation characteristics of a junction beam have been performed in a wood building. The in-situ nature of the measurement has brought some limitation, especially because of the reflections of the vibrations waves against the walls. On another hand, this was also a unique occasion to get an idea about how building elements made of would interact with each other in an actual modern construction.

It has been shown that impact vibration waves propagate well in the horizontal direction through the junction beam, as the acceleration magnitudes measured on the floor of the adjacent room reaches almost 50% of the magnitude before the junction. In contrary, the levels measured against the walls in all rooms (except the excitation room) are quite low.

The very special *Limnologen* setup can allow a rich set of measurements of sound and vibration propagation in a wooden building. Further studies on this topic could help a lot to understand the pros and cons of lightweight constructions of timber materials, and of course, to make them better, in terms of sound and vibration insulation.

6 ACKNOWLEDGEMENTS

This work was founded by the foundation CBBT (CBBT is a Swedish abbreviation for "Centre for Building and Living with Wood").

7 REFERENCES

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The sound insulation dependence of floor level in a high-rise wooden building

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ABSTRACT

The trend to build higher wooden houses with high performance gives new challenges. To combine a good stability of the house with high sound performance is essential. To be successful, an efficient understanding for both statics and acoustics are needed. This paper investigates the sound insulation of a modern wooden house. The multi family house has seven stories that are constructed with wood. The quality of the sound insulation is expected to be higher than usual building regulations as the owner requested so. The sound reduction index and impact level were measured between similar flats placed above each other. Also the attenuation for a modern floor structure in the building was measured. It is shown that the attenuation for the modern solution is not much influenced from the beams of the floor structure.

1 INTRODUCTION

For high-rise wooden buildings the largest acoustical challenge is to avoid impact noise and especially flanking transmission. The project Limnologen is a part of Välle Broar project in Växjö, Sweden. Välle Broar is a part of the city where wood buildings are built with modern technique. The aim is to develop the industrial building technique for houses built with wood since wood is thought to be an environmental friendly material.

In this case study the impact sound level and sound reduction index were measured between apartments in the vertical direction at Limnologen. The measurements were made at different heights in order to see if there exist systematic differences. The flanking transmission in the building was limited by putting elastomer under the floors elements. The flanking path will thereby be less announced. In the lower parts of a high building the load on the elastomer is higher and therefore a stiffer elastomer was used there than higher up in the building. It is thought that these different stiffeners of the elastomers will make the vertical sound transmission to differ.

This study includes an examination of the vibration pattern of the floor structure. Studies of stiff wooden floors have been performed earlier by Salmela and Olsson [1]. They examined a wooden floor structure construction that was built to have a high stiffness in both main directions. They showed that this type of floor structure have very low damping. The present floor structure has a thick top plate and can therefore also be rather stiff, although not as the floor structure presented by Salmela and Olsson. The attenuation of a common wooden floor structure have been studied by Sjökvist and Brunskog [2]. They showed that the attenuation for a typical wooden floor structure is very high in the direction across the beams. Since the

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present floor structure is much stiffer the attenuation will differ a lot from that study. Studies of vibrations on wooden floors have also been made extensively by both Nightingale et al. [3] and Chung et al. [4]. It is interesting to examine how this structure vibrates in order to gain more knowledge about vibration and sound transmission in lightweight structures.

In a companion paper [5] a study of the flanking transmission is made in the same house at Limnologen in Växjö.

In the present study the word "floor" and the construction "floor structure" have to specific different meanings. Floor is used only to refer to the height inside a building, e.g. between the ground floor and the first floor is a floor structure built.

2 METHOD

The building Limnologen will consist of four eight-storey buildings that are built with seven stories of wooden structure. The ground floor is built with concrete. The architectural plan is the same for floor 1 to 5, see figure 1. At floor 6 an extra stair leaves from the living room up to

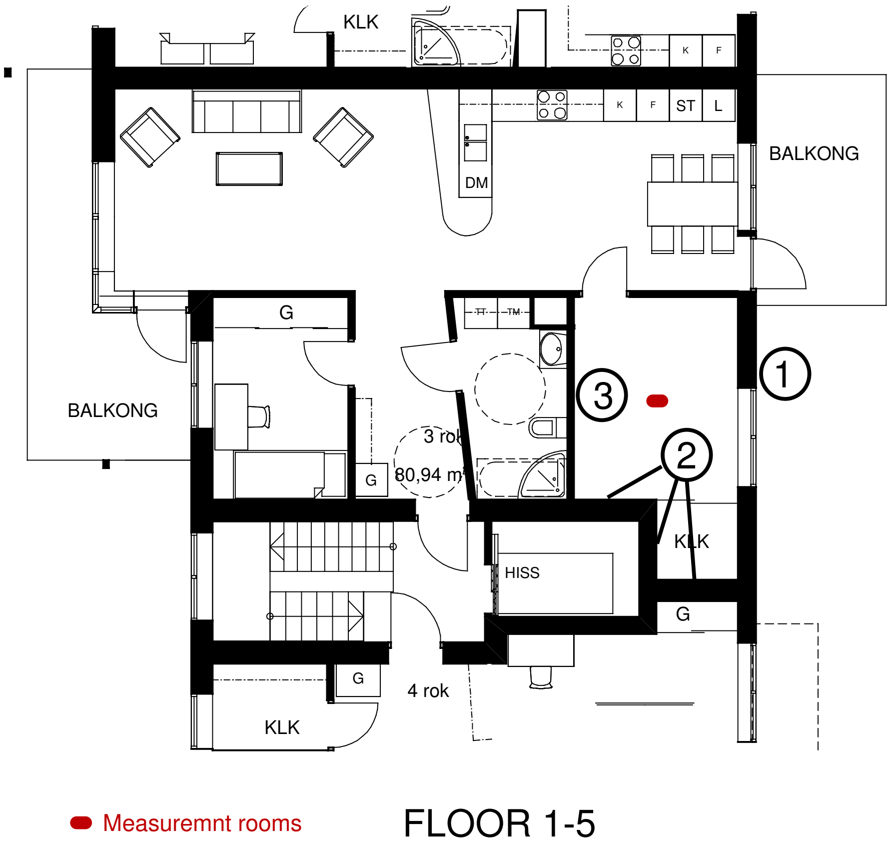

Figure 1: A part of the drawing for the house Limnologen. The sound reduction and the impact noise was measured vertically between the rooms marked in the drawing.

a top part for that apartment. Considering that the ground floor is made with concrete, six floors have nominally the same constructional details. The largest acoustical difference is thought to be the different elastomers that are placed to control the flanking transmission. The elastomers used had different properties at different floors and also at different walls. The elastomers used

Table 1: The placement of elastomers in the building. The wall numbers refer to the numbers in figure 1. The properties of the elastomers can be seen in table 2.

Floor	Wall 1	Wall 2	Wall 3
2	Sylodyn NF	Sylomer T	CB 14-R
3	Sylodyn NF	Sylomer T	CB 14-R
4	Sylodyn NF	Sylomer V	Sylodyn NF
5	Sylodyn NF	Sylomer V	Sylodyn NF
6	Sylomer T	Sylomer V	Sylodyn NF

Table 2: The properties of the used elastomers.

Elastomer	Loss factor	Density [kg/m^3]	E-module Static [MPa]	E-module 30Hz [MPa]
Sylomer T	0.13	820	9.1	12.3
Sylomer V	0.13	680	4.5	6.4
Sylodyn NF	0.10	840	16.2	18.8
CB 14-R	not exactly known, but stiffer			

between the measured rooms was Sylomer V, Sylomer T, Sylodyn NF and CB 14-R at places shown in table 1. Some properties of the elastomers are shown in table 2.

The floor structure of the building is different from classical floor structures that uses regularly placed wooden beams connected to a top plate of chipboard. Details of the present floor structure can be seen in figure 2. The present floor structure has a 73 mm thick plate made of laminated wood on the top. The beams are made with a flange to make them extra stiff, and they are also not periodically placed. The floor structure was prefabricated and transported to the building site where it was mounted.

2.1 Measurement set up

Several measurements were made in order to evaluate the acoustical behavior of the building. The sound reduction and impact noise were measured between several stories to obtain the influence of the different elastomers used to combine vibration damping with correct static load bearing. The vibration pattern of the floor structure was measured for one of the larger floor structures

The vibration pattern of a floor structure was measured at random points in an area that was 4 times 4 meters. The random placement was used since then conclusions from the study are valid over the entire measurement area. The randomization was performed to get 96 measurement points within the measurement area. One point of excitation was also chosen at point (2,0.8), which is near the middle of a bay and in the middle of the measured area. The x axis is along the beams. The tapping machine was used for excitation. However, only one hammer was used in order to minimize the spatial spread of the excitation. A picture of the setup is shown in figure 3. There one can also see that the floor structure has traces on the top, so the surface of the top plate was not exactly flat. Accelerometers as shown in figure 4 was screwed to the floor at the random measurement points with two screws. They were all placed with the same orientation towards the cartesian coordinate system.

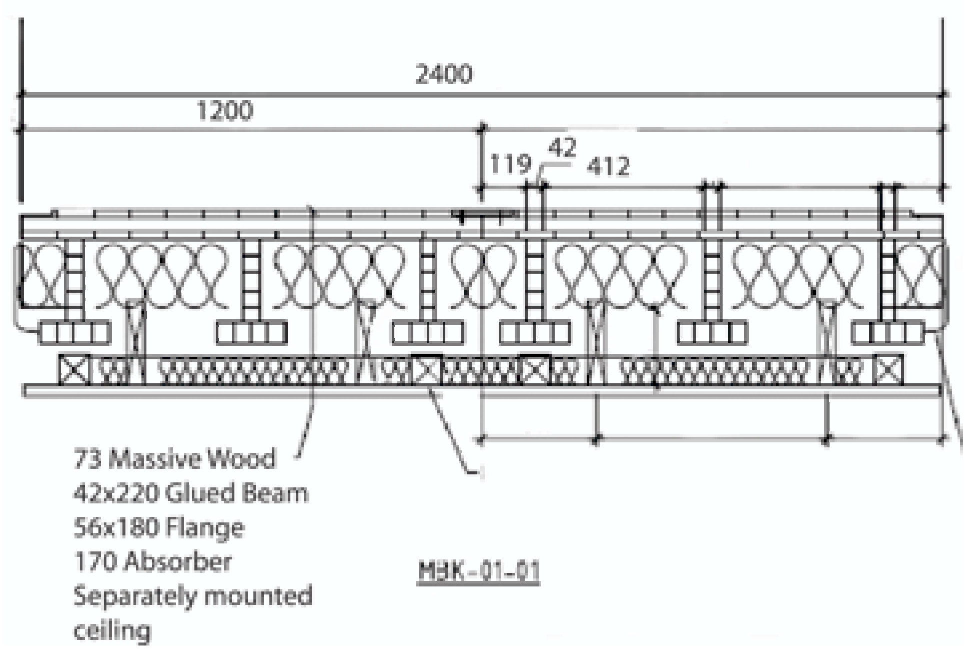

Figure 2: One element of the measured construction. These elements where joined to build the whole floor structure.

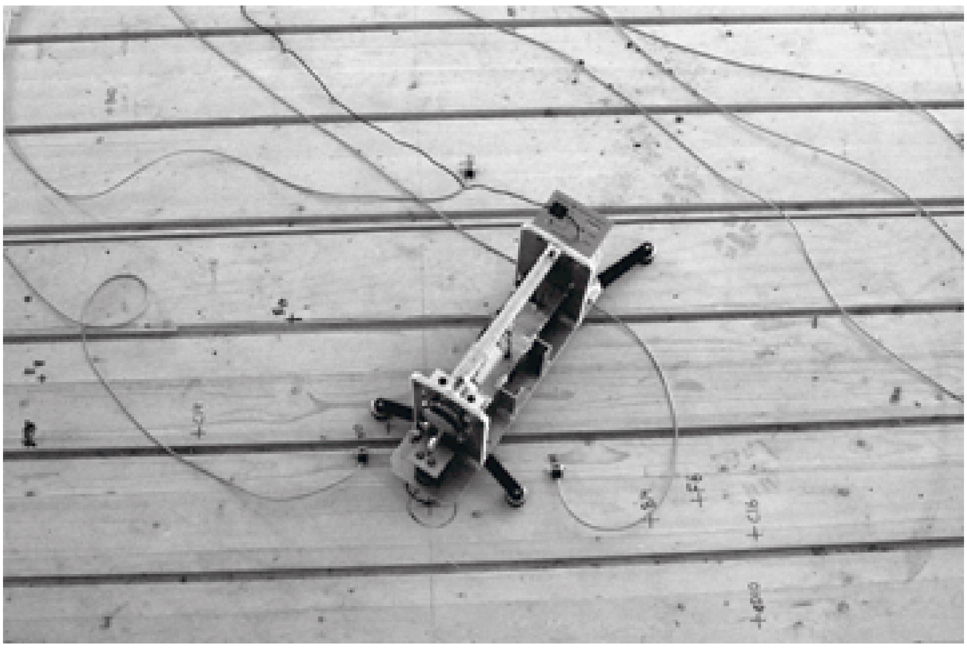

Figure 3: The measurement setup near the point of impact. The picture is taken a bit from above towards the floor structure with the tapping machine. One can also see the traces made in the top plate. Some of the accelerometers closest to the point of excitation can be seen as well.

Figure 4: The accelerometers were screwed into place by two screws. The orientation was always the same.

3 RESULT

3.1 Sound reduction and impact noise

Figure 5 shows the difference of the impact level due to floor in a eight-story house. The measurements were performed with the floors one to five as receiving rooms. The difference is shown as decibel per floor. Between 250 and 500 Hz are therefore the mean difference between 1 and 2 dB. One can therefore expect an impact sound level difference between the ground floor and the top floor of more than 10 dB in this frequency range, considering that it is an eight-story house.

Figure 6 shows the difference of the sound reduction due to floor in the same eight-story house. The measurements were performed with the floors one to five as receiving rooms. The difference is shown as decibel per floor. The confidence interval for these results had approximately a 10 dB range. The mean values varied for the measured 1/3-octave bands within the range -2 to 2 dB per floor. Positive values mean that the sound reduction was higher between floors higher up in the building.

3.2 Vibration Pattern

The vibration pattern was measured for one floor structure area that that measured 4 times 4 meters. The attenuation was calculated with its 95% confidence interval. The calculations was made for directions along the beams and orthogonal towards the beams. The resulting attenuation can be seen in figures 7 and 8. The attenuation is very weak for the present floor structure. Mostly the attenuation was well below 0.5 dB per meter.

Figure 9 shows the average damping from divergence.

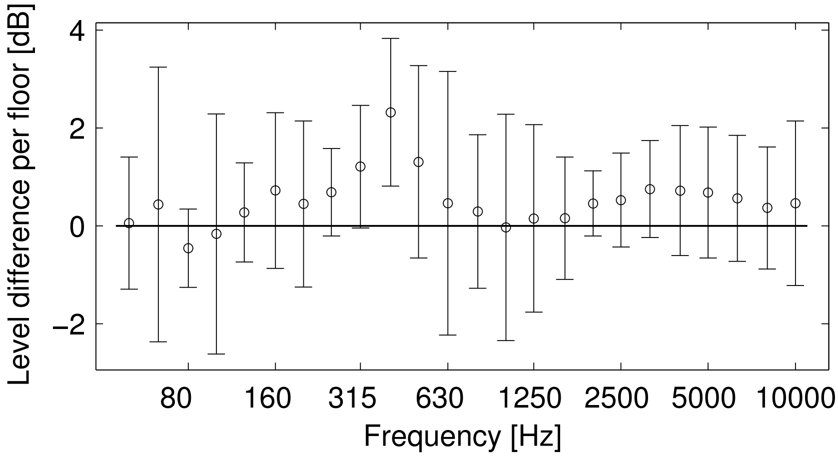

Figure 5: The difference of impact sound insulation between the floors, mean values (circle) and its 95%-confidence limits, for each 1/3 otcave band. Positive values means higher impact sound level at higher floor.

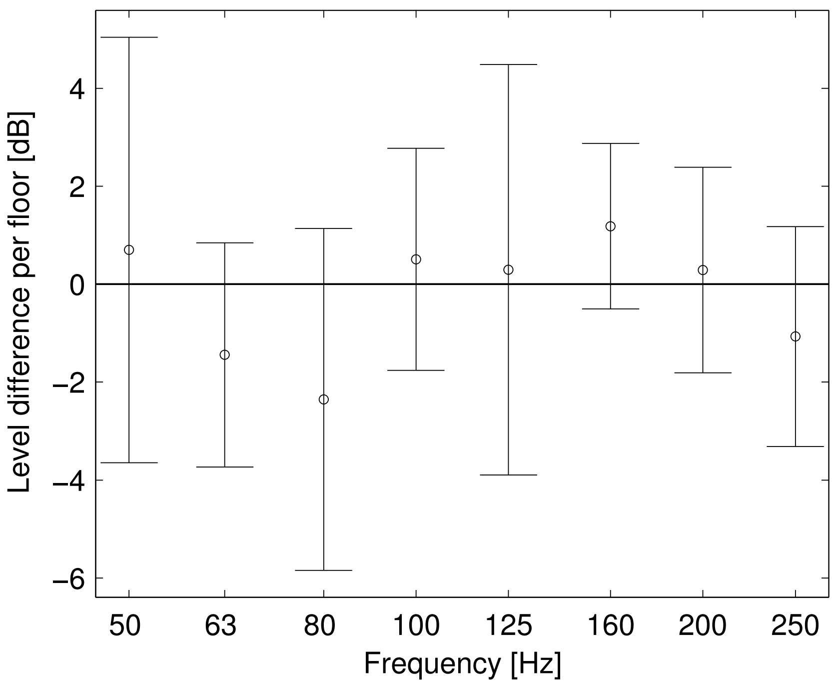

Figure 6: The difference of sound reduction between the floors, mean values (circle) and its 95%-confidence limits, for each 1/3 octave band. Positive values means higher sound reduction level at higher floor.

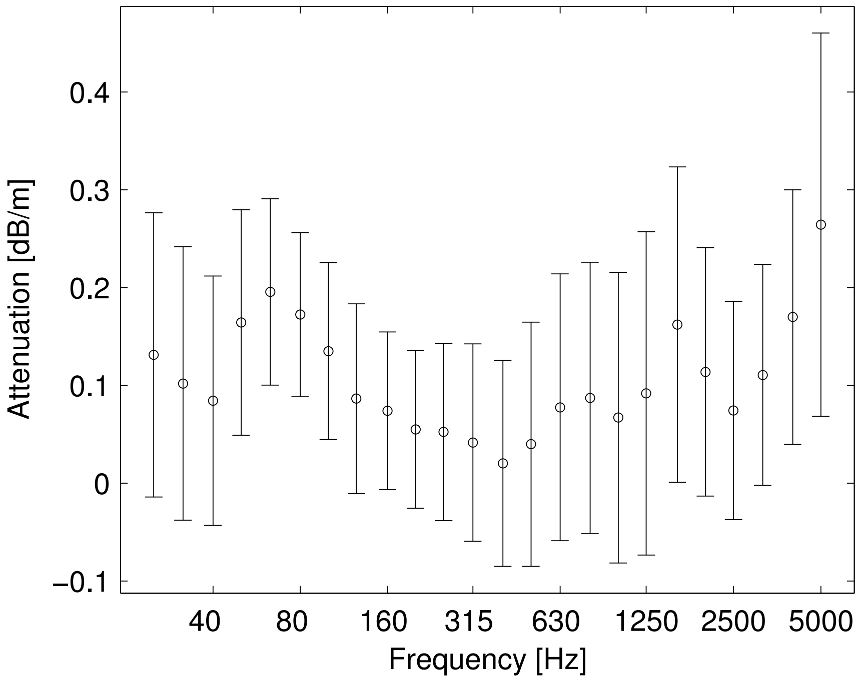

Figure 7: The mean attenuation in the direction along the beams (circle) together with its 95% confidence interval.

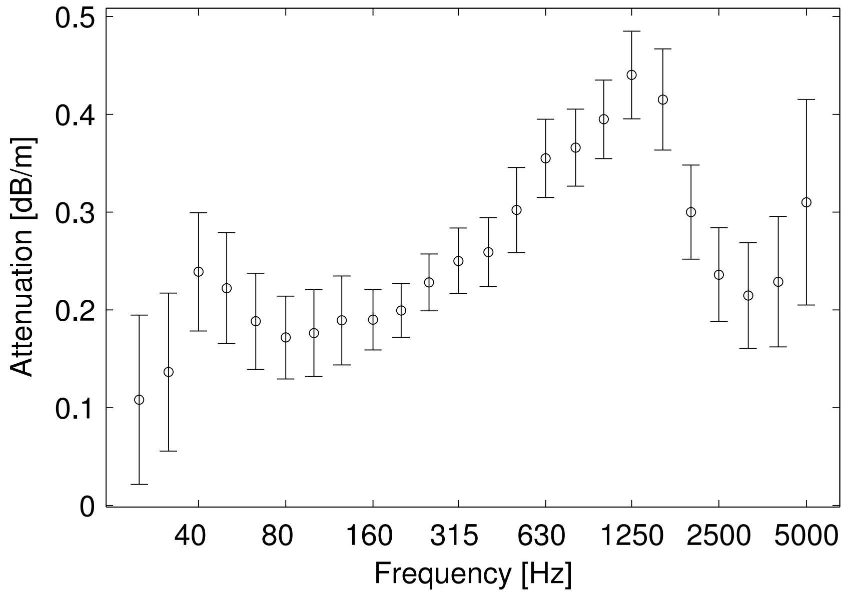

Figure 8: The mean attenuation in the direction across the beams (circle) together with its 95% confidence interval.

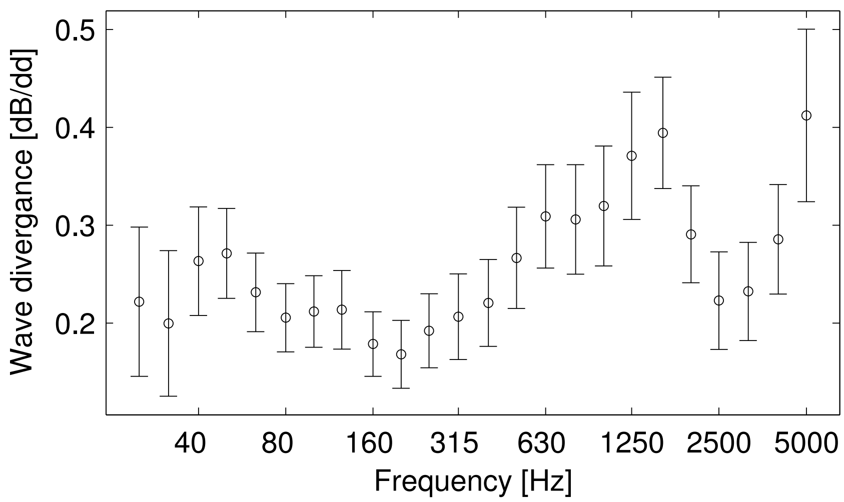

Figure 9: The mean wave divergance away from the exitation and the corresponding 95% confidence interval.

4 DISCUSSION

The attenuation for the present floor structure was low compared with common joist-beam structures. The attenuation was also approximately the same in both the main directions. The average damping from divergence seems to be strong compared with the attenuation in the main direction. It is therefore likely that the upper plate mainly governed the vibration pattern and that the beams did not have much influence of the vibration pattern for this floor structure. The upper plate of the floor structure was probably to thick for the beams to make any major impact for the vibration pattern.

The sound insulation between floors was measured with both airborne noise and impact noise. The results in figures 5 and 6 show that the sound and vibration insulation might not be as much influenced of which floor were measured. Since the construction was made with softer elastomer between the upper floors and harder elastomer between the lower floors one can expect to see a difference. The measurements here could though not confirm any regular differences. Although indeed there are large differences between apartments that are nominally the same except for the elastomer. But variations from the construction and measurement technique were too large to discover major regular differences caused by the different types of elastomers.

5 ACKNOWLEDGEMENT

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