Sound Attenuation in a Sandwich Floor

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Abstract

In modern building construction, where light weight structures are preferred for cost reasons, the sound transmission is often a problem to be considered carefully, hence the many studies addressing this issue. A common floor construction in a lightweight building system is using chipboard plates attached to wooden beams by screws and glue. One drawback with such a system is the propagation of vibrations stemming either from harmonic excitation like surround systems especially at low frequencies and/or transient excitation like human walking. In order to accurately predict the sound attenuation and the losses of such building systems, computationally accurate and efficient simulation techniques are needed. The main objective of the present work is to examine sandwiched floor constructs consisting of one and two layers of chipboards attached to supporting wooden beams. Discontinuities between adjacent boards and between boards and beams are of special interest. On one hand, they affect the kinetic energy loss, due to the acoustic attenuation of evanescent waves in the structure. On the other hand, they also alter the phase shift of the waves as they travel past the different types of discontinuities in the floor assembly. A series of measurements have been performed using two-axis accelerometers distributed over the floor and recorded synchronously. A special focus has been put on investigating the low frequency range (10-600Hz), including transient loads.

Introduction

As lightweight constructions get more and more popular for the obvious reasons of the low cost and ease of construction, noise propagation is and remains an issue in light frame buildings [1]. This challenging problem finds its origin in the low weight, density and stiffness compared to traditional materials. Consequently, more nuisances are reported, related to sound transmission, that might cast a undesirable shadow of discomfort over the lightweight building industry.

Due to the large surface they offer, and to their primary function, floors play naturally an important role in terms of sound propagation. Therefore, it is also critical to understand precisely how sound and vibrations are conducted, transmitted or absorbed by floors. The properties of floors depend strongly on their structure [1-4]. This new study proposes to investigate the behaviour of a sandwich floor. As in former studies [2-3], arrays of accelerometers have been used to simultaneously sense the vibrations at different points along the floor, resulting from a single point excitation. In this case, however, we use a shaker as the excitation rather than a tapping machine.

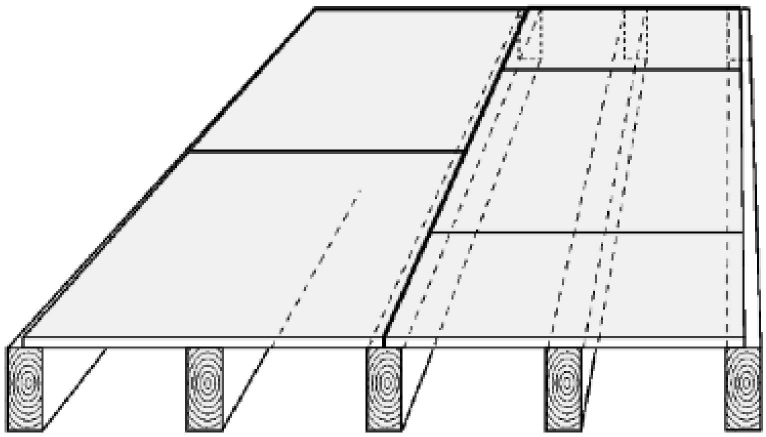

Figure 1: Construction of the floor structure.

Experimental Setup

Floor construct

The floor construct is made from chipboard plates on top of spruce beams. The plates are attached to the beams using screws every 300 mm. This is a common type of floor constructs in modern lightweight building systems in Sweden.

The dimensions of the plates are 1200x2400x22mm and the dimensions of the beams are 60x215x5400mm. In addition to this construct, we have also investigated the case where an additional layer of chipboards has been added on top of the first one. This type of sandwich floor constructs is common in rooms with stricter demands on durability and stiffness i.e. in bathrooms. Figure 1 represents a schematic view of the construct. Note the discontinuities between the different plates.

As the second layer of chipboards is added, the plates in the second layer are shifted to the right with respect to the first layer so that no discontinuities are directly on top on another. The actual floor can be seen in figure 2 and the placing of the second layer can be seen

Figure 2: Picture of the actual tested floor.

Figure 3: Placement of the floors layers within the floor.

Figure 4: The beams and their supports, seen from below the floor.

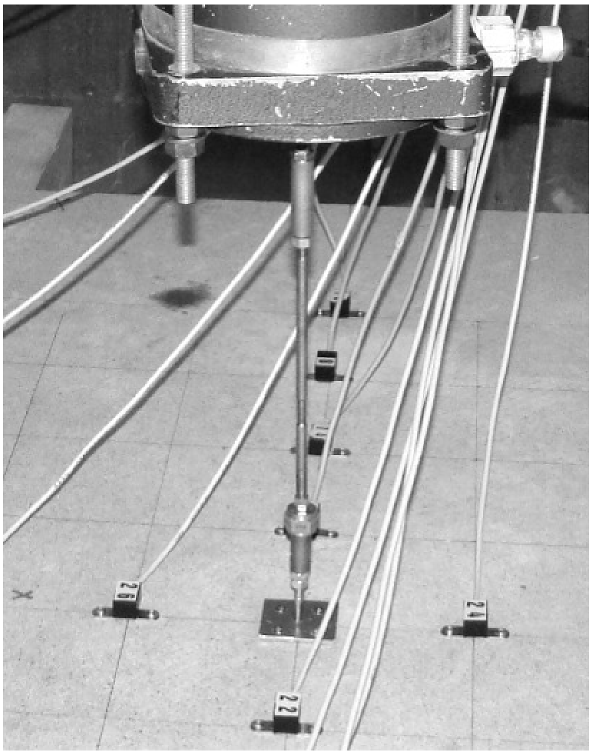

Figure 5: The shaker and the accelerometers surrounding it.

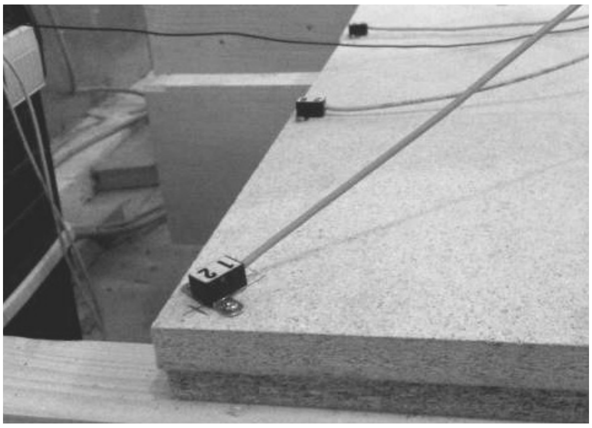

Figure 6: Array of accelerometers along the borders.

in figure 3.

The beams are placed on triangular supports one in each end of each beam and the whole construct is slightly raised above the floor in the test room enabling easy access to underneath the floor as can be seen in figure 4.

Accelerometer setup

The measurements were performed using 27 two-axis accelerometers uniformly distributed over the floor. The accelerometers were placed with 300mm spacing in the direction across the beams and with 600mm spacing along the beams as shown in figure 5. This spacing has been determined to be a good compromise between the spatial resolution and the area covered by the sensor array, given the range of the frequencies we wanted to investigate.

An additional set of 7 accelerometers were placed on the beams, five on the middle of the beams and two placed on the beams on either side of the first shaker position.

As the vibrations in the beams have a much lower magnitude than in the plates the accelerometers on the beams have a higher sensitivity but lower bandwidth (1500Hz compared to 5000Hz). To get the force applied by the shaker a B&K 8200 force transducer was used placed between the shaker rod and the plate attachment as shown in figure 5.

The accelerometers and the force transducer are connected to a computer with a 32–channel acquisition system. The system is capable of synchronous measuring of all the channels up to 100kHz sampling frequency and stores the data in a large and fast temporary buffer before it is transferred to the computer. The acquired data is saved as MATLAB .mat files for later analysis.

In order to get a finer grid over the floor the accelerometers are arranged in a set covering one third of the floor, this set is displaced twice and the measurement repeated accordingly at each position. This whole setup is then repeated for the second shaker position. As the measurements are performed in three different sets the synchronicity over the complete set of accelerometers is lost but is retained within a set.

In order to investigate the behaviour of discontinuities, two other sets of measurements were performed, where the accelerometers were placed along the borders between different plates, as shown on figure 6.

We have also made some walking experiments where two test subjects one male and one female walked over the floor with hard shoes, barefoot and in the case of the male subject with rubber (soft) soles. The test subjects traversed the floor across the beams, on a path between two beams and also on top of one beam.

Measurements

Mode excitation

The very advantage of using frequency sweeps as excitation signals for the shaker is that different floor vibration

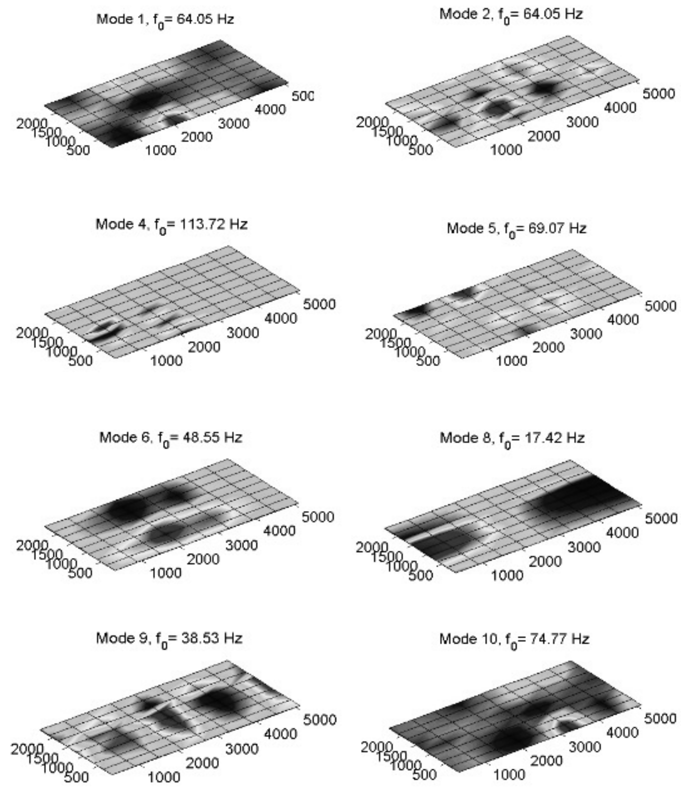

Figure 7: Accelerometer magnitude density plot for the onelayer floor for excitation frequencies corresponding to modes 1, 2, 4, 5, 6, 8, 9 and 10.

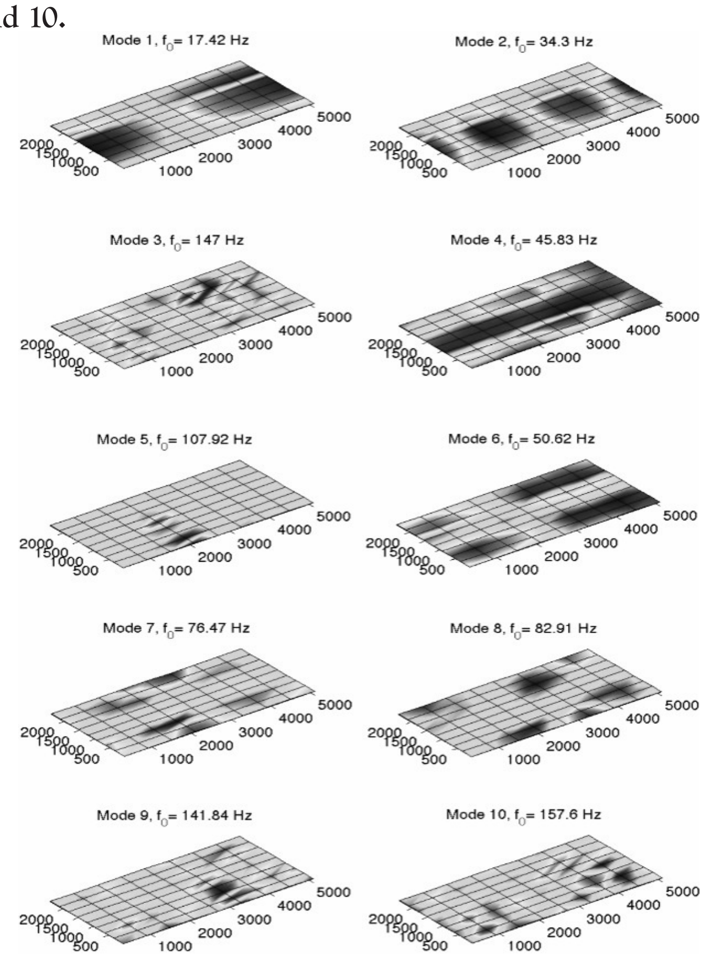

Figure 8: Accelerometer magnitude density plot for the twolayer floor for excitation frequencies corresponding to modes 1 through 10.

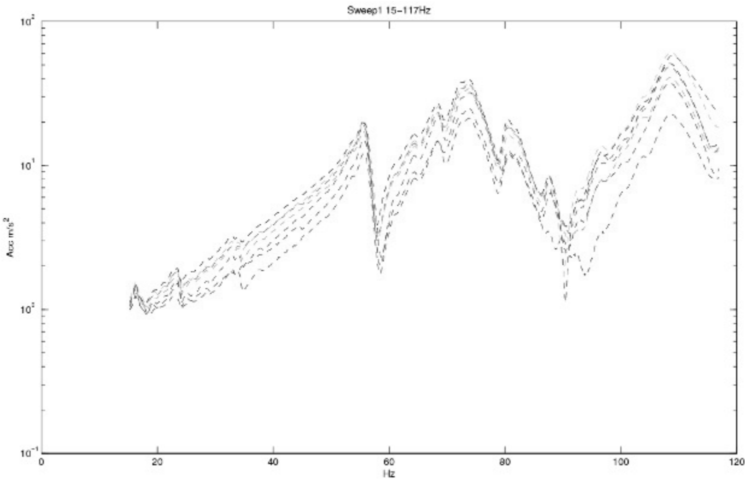

Figure 9: Accelerometer magnitude for a sweep between 15 and 117Hz.

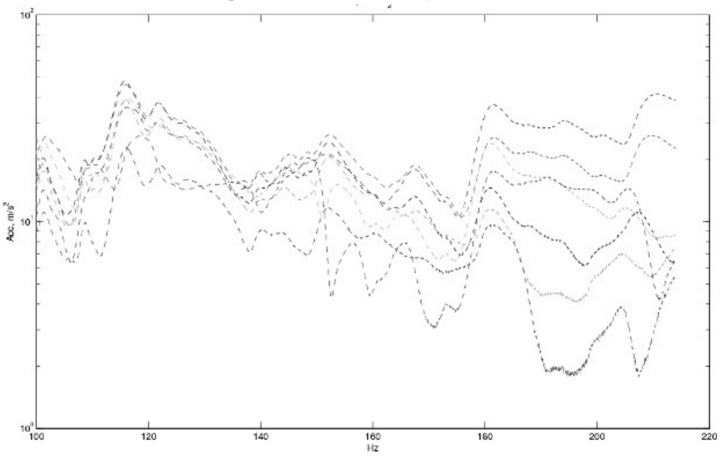

Figure 10: Accelerometer magnitude for a sweep between 100 and 214Hz.

modes get excited as the frequency is increased progressively. Figure 7 represents the acceleration magnitude density plot for the excitation frequencies corresponding to some of the first modes in the case of the one-layer floor. Figure 8 represents the same information for modes 1 through 10, but in the case of the two-layer floor. As it can be observed, the vibration repartition over the floor is modified drastically as various modes are excited, even though the frequency is sometimes just slightly modified.

Frequency sweeps

While the former section showed results with a focus on the spatial distribution of the vibrations, we now focus solely on how the magnitude varies with the frequency as a sweep is applied to the shaker. The figure 9 represents the frequency response of 8 accelerometers as the excitation frequency is increased continuously between 15Hz and 117Hz. The modes can be easily identified here as well, and since the spatial frequency is low, all channels show their minima and maxima at roughly the same frequency.

In figure 10, a similar measurement result is represented, using the same channels, but for a sweep frequency range of 117-214Hz. One can notice that the magnitude changes get out of synchronization as the frequency increases, what makes fully sense, since the spatial frequency also increases as higher order modes are excited. Therefore, small position differences count for high magnitude differences.

Floor discontinuities

Using a large number of accelerometers all over the floor plates allowed us to observe the evolution of the floor behaviour across the discontinuities as the frequency was varying throughout the sweep frequency range of the shaker excitation signal. The next three figures (11, 12 and 13) represent 2-dimensional maps with contour plots of the acceleration magnitude over the plates. Three excitation frequencies have been chosen as representative of the phenomena taking place.

For each frequency, the results are shown with the shaker in either of both tested positions (top versus bottom figures). Finally, and most importantly, the results with one-layer floors and two-layer floors are systematically compared (left side versus right side figures). The dimensions of the plates are outlined by white lines superimposed to the 2-D maps.

Figure 11 represents the measurements for the lowest available frequency of 15.87Hz. Absolutely no attenuation is to be observed across horizontal discontinuities between the plates.

On the contrary, the attenuation across the vertical discontinuity is relatively significant, which is expected, since the plates are attached to the beams

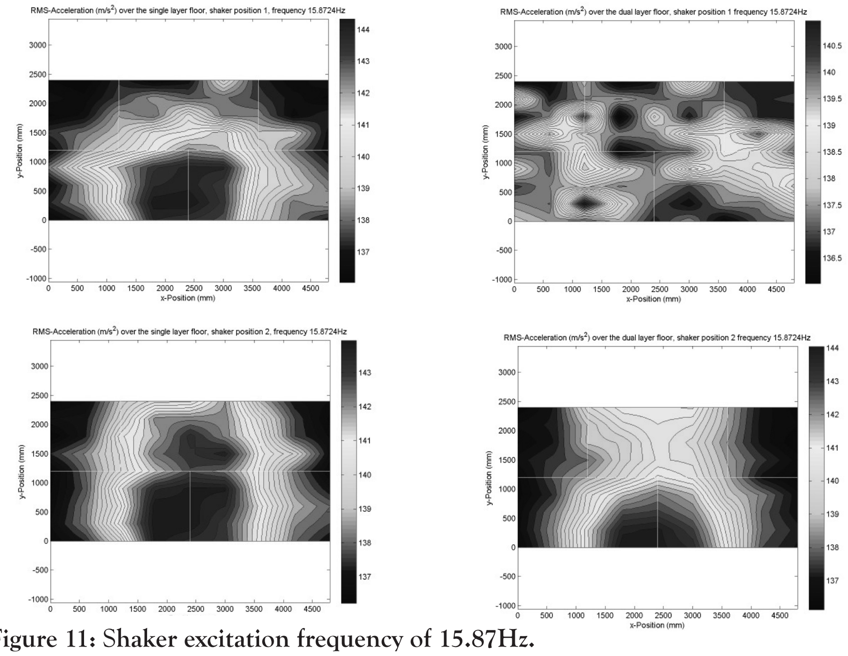

Figure 11: Shaker excitation frequency of 15.87Hz.

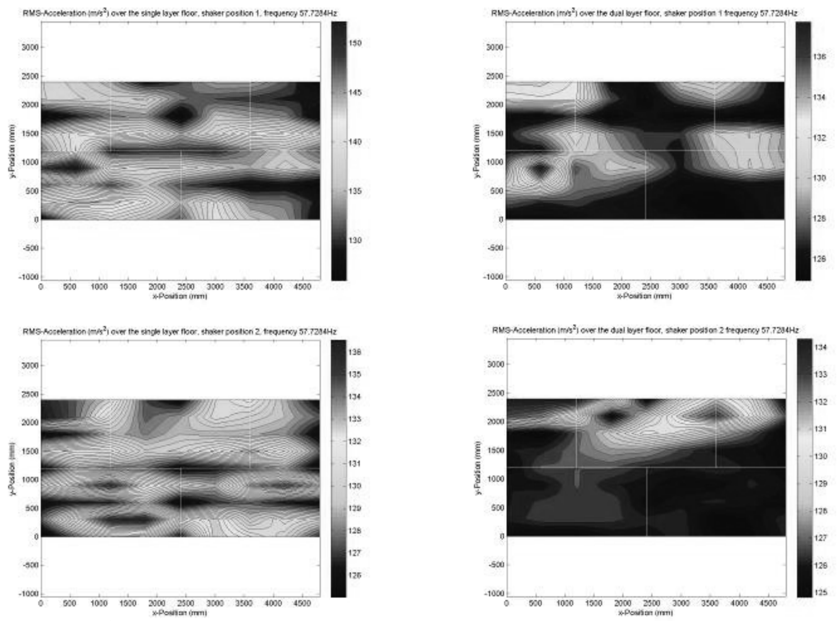

Figure 12: Shaker excitation frequency of 57.73Hz.

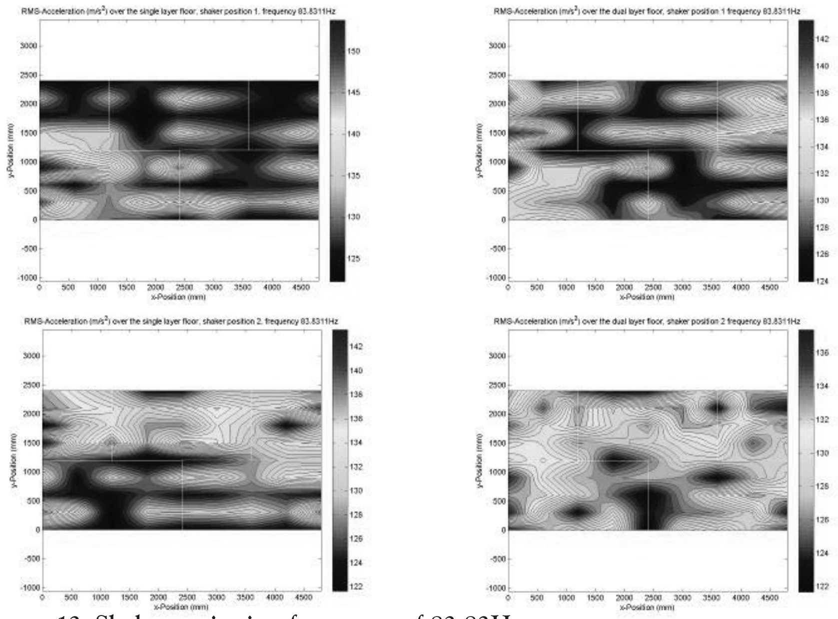

Figure 13: Shaker excitation frequency of 83.83Hz.

precisely along this line.

When comparing the one-layer configuration (left) with the two-layer configuration (right), one notices that the vibrations are much more localized and propagate less far in the case of the double layer floor. In the case of the first position of the shaker (top right), one can even see that the dominant mode is of higher order compared to the one-layer case (top left).

Figure 12 corresponds to measurements done at a higher frequency of 57.73Hz. Interestingly, this frequency appears to excite modes in such a manner that the upper left extremity of the floor is subject to high vibration levels. Nevertheless, it also appears clearly that the vibration is much more localized in the case of the two-layer floor (right) compared to the one-layer floor (left).

Finally, Figure 13 corresponds to a similar measurement, but at an even higher frequency of 83.83Hz. In this case, where higher modes are dominant, the tendency seems to be reversed, as the vibrations seem to stay slightly more localized in the one-layer case (left), and this for either shaker position (top or bottom figures).

Foot steps

The signals from the accelerometers along five beams have also been recorded while a person weighing 81kg was walking on the plate above, on a path between the 4th and the 5th beams. Figure 14 represents the signals from the accelerometers over the time. Whereas the first impact vibration is quickly attenuated when we get further from the walking path, the lower frequency vibration occurring while the foot is already in contact of the floor propagates very well over the whole structure and is merely attenuated, or even gets larger at the opposite end of the plate (top curve).

CONCLUSIONS

An extensive study of vibration propagation in a floor over a wide range of frequencies has been done. A comparison of a one-layer structure and a two-layer structure allowed us to make some interesting observations and to draw instructive conclusions. It has first been established that the dominant mode at a given frequency is

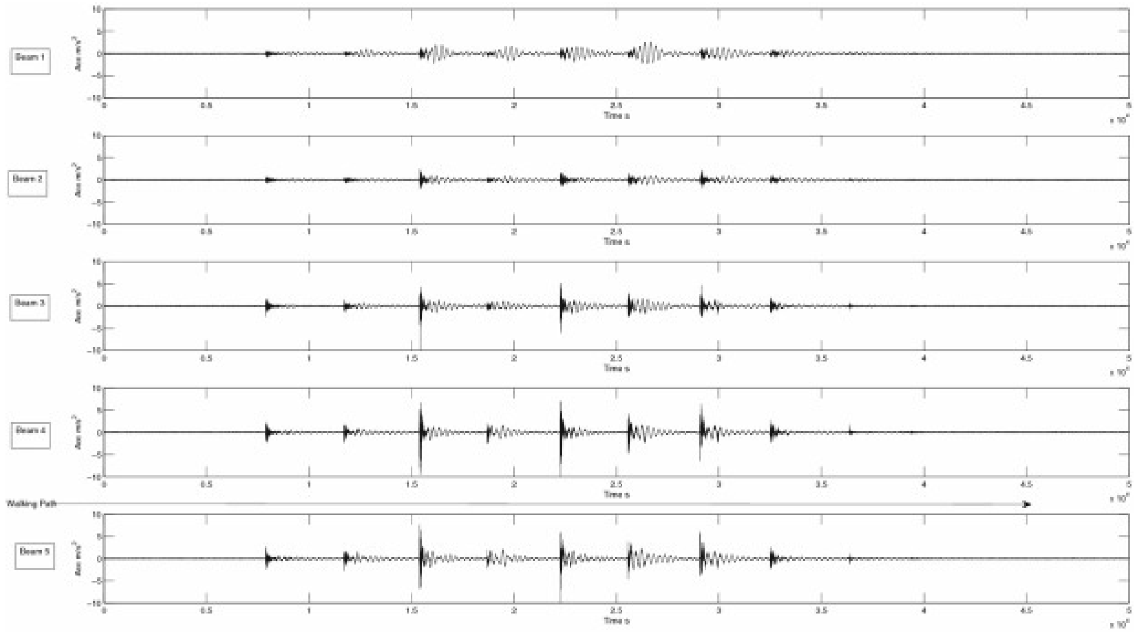

Figure 14: Accelerometer magnitude over time, recording steps.

strongly affected by the type of structure used. Then, as the dependence with the frequency has been investigated over several adjacent accelerometers, it has appeared obvious that the magnitude spread is drastically increased with the frequency, since the spatial frequency also increases. The most interesting part is probably the comparison of 2-dimensional magnitude plots for one-layer floor structures versus two-layer floor structures. The analysis shows that the propagation of the vibrations over the floor at lower frequencies is significantly lowered by the adjunction of a second layer that does not exactly overlap with the first one.

At higher frequencies, however, this does not seem to hold any more, the tendency even seems to reverse, the vibrations propagating further in some cases. Finally, the practical case of a person walking on the floor has been investigated, and the investigation of the recorded accelerometer signals shows that the vibrations resulting from the first impact are well absorbed and their magnitude quickly decrease, but the magnitude lower frequency component resulting from the contact of the foot on the floor is merely decreased, if at all, over the span of the floor.

References

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