INTER-NOISE 2006
3-6 DECEMBER 2006
HONOLULU, HAWAII, USA

Low-frequency vibration measurements on LTF floors.

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ABSTRACT

In Australasia multi-storey, multi-residential light timber-framed buildings suffer from poor low-frequency impact insulation compared to their concrete counterparts. This poor impact performance is currently inhibiting the uptake of multi-residential light timber-framed buildings. A research programme involving Australian and New Zealand funding agencies and companies was set up to improve low-frequency impact insulation of timber-framed floors. As part of this research programme, detailed surface vibration measurements using a scanning laser vibrometer were made of various timber-framed floors. In this paper, we will show the results of some of these measurements to illustrate certain aspects of vibration propagation in the floor structure.

1 INTRODUCTION

In this project we were primarily concerned with examining the weakest area of timber floor impact sound insulation performance: low-frequency impact sound. It is difficult to measure low-frequency sound performance of a floor using traditional methods of measuring the sound pressure in a receiving room and normalising for the effect of the room. This is simply because the effect of the room is uncertain at such low frequencies and hence is difficult to factor out.

With the above in mind, and because we would like to examine the performance of the floors in detail, it was decided to measure the vibration response of the floor when driven or excited with a known force. This allows the effect of the room to be removed, and if we measure the vibration of the floor over its surface, also allows us to examine how the floor is reacting to the applied forces. This detail of measurement assists greatly in modelling and generally seeing what is happening in the floors.

The technique presented in this paper was used to provide information to enable development of LTF floors with improved low-frequency impact insulation. A report which contains information about other aspects of the project has been completed [1].

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2 EXPERIMENTAL SETUP.

The floors were built in a concrete test chamber. On each floor an electrodynamic shaker was used to provide a vertical force on the floor upper surface. The shaker was connected to the floor through a wire stinger and a reference force transducer. The function of the stinger is to ensure that only vertical forces are transmitted in the floor, while the force transducer enables us to known how much force is being sent into the floor. The shaker body was mounted on a beam which straddled the floor and rested on supports which sat on the concrete collar surrounding the floor. Vibration isolation of the beam from the concrete collar was provided by very resilient pads made of polyester fibre infill. The shaker was driven with pseudorandom signal with a bandwidth from 10Hz to 500Hz, for a duration of 2 seconds (to get a frequency resolution of 0.5Hz). The shaker setup used to achieve this is shown in Figure 1.

Figure 1: View of the shaker attached to a floor to send vibrations into the floor.

A scanning laser vibrometer (Polytec PSV 300) was used to measure the velocity of the floor and ceiling normal to the surface. A grid with a spatial resolution of 10-14cm was used to obtain a map of the surface velocity of the floor and ceiling relative to the input force; both amplitude and phase information was recorded at each frequency. The scanning laser vibrometer used to measure the vibration of the upper surface of the floor is shown in Figure 2. The scanning laser vibrometer was also used to measure the vibration of the ceiling surface and this set up is shown in Figure 3.

Figure 2: Overview of the shaker and the scanning laser vibrometer for measurement of floor vibration response. The scanning laser vibrometer is mounted on a movable trolley which can move along a gantry made from I-beams. There are two gantries to enable the whole upper surface of the floor to be scanned.

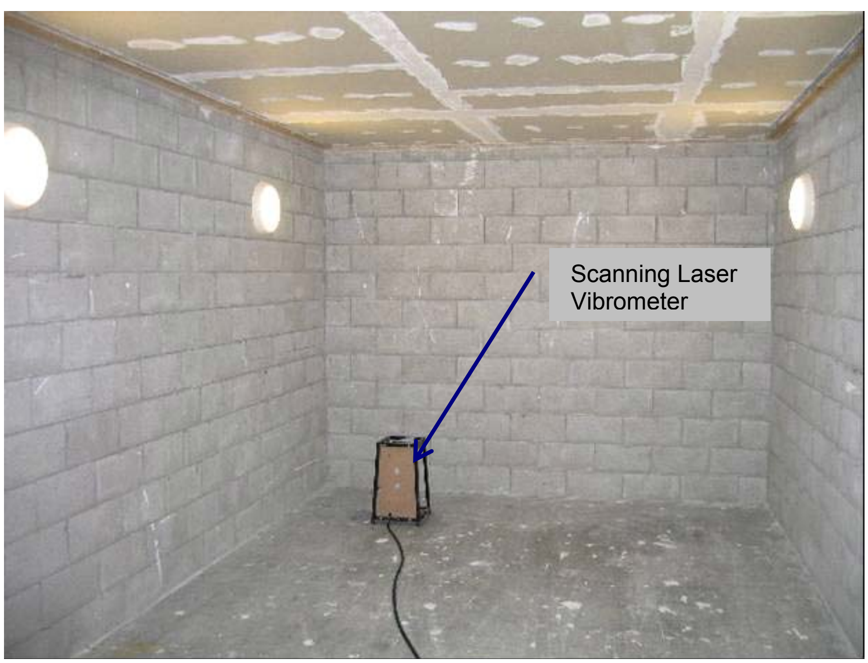

Figure 3: The scanning laser vibrometer as used to measure the vibration of the ceiling in response to the shaker force. The vibrometer is moved around on the floor to cover the whole ceiling.

3 EXPERIMENTAL TECHNIQUE

For each floor, the shaker was connected to the upper surface through a force transducer. The position on the floor was selected so that the low-frequency modes would be excited. Only one position on each floor was chosen. It is often useful to select two or more positions on a structure to ensure a sufficient number of modes are excited, and to act as a check for results. However, in this case, it would have taken too long to do two complete vibration response scans of each floor.

Once the shaker was connected to the floor the scanning laser vibrometer was positioned over the floor upper surface to measure the surface velocity of the floor upper in the direction normal to the surface of the floor. The scanning laser vibrometer was supported in a mobile cradle and mounted on two gantries over the floor so that it point down to the floor and scan the surface. For each can the area that could be measured was about 1.8m by 1.8m; eight positions were required to scan the whole surface of the floor. The scanning laser vibrometer measurement equipment was also connected to the force transducer so that the recorded surface vibration is normalised with respect to the force applied. The signal sent to the shaker was a pseudorandom noise filtered by a low-pass filter (500Hz corner frequency) with a period of 2 seconds (±30μs), which matched with the sampling time of the laser vibrometer software. This ensured minimal spectral leakage and a frequency resolution of 0.5Hz.

After measuring the upper surface, the scanning laser vibrometer was placed in its cradle on the floor under the ceiling of the floor to be tested, pointing up to the ceiling. It was then used to scan the surface of the ceiling. This was repeated in different positions to cover the whole ceiling.

After the scans of the floor vibration were made, the results of the measurements of surface vibration over the floor were extracted from the Polytec scanning software into a form easily readable by other software. The program used to do this was specially written for the project. The data was then compiled by software specially written for this project to enable overall surface velocity of the floor upper and ceiling to be plotted as well as animated pictures of the response of the floor upper surface and ceiling to be generated.

4 EXPERIMENTAL RESULTS

One of the important results of doing vibration measurements on the test floors, as was done for this project, is that we can see the shapes of vibrations which are being produced. This enables us to identify the modes which are producing resonances and to have a deeper understanding of what is happening in a floor. This is particularly useful for developing a theoretical model of such floors.

In this section we examine a few mesh plots of the results of the measurements of some floors to illustrate a few features found in the vibration of floors. Obviously the data produced was enormous and we can only hope to pick a few points in the hope that they will be illuminating.

4.1 Simple floor – panel on solid joists.

We start by examining a simple floor: 15mm plywood screwed to 300mm deep LVL joists spanning 5.5m and which are spaced at 400mm centres. The floor has no ceiling. Figure 5 is a photograph of the simple floor.

Figure 4 shows the average surface velocity of the floor upper surface as a function of frequency. From this plot we can pick out resonant frequencies in the floor.

Figure 6 shows the vertical displacement of the simple floor for a frequency which appears to match the eigenfrequency of the fundamental mode (1,1). As we go up in frequency we find the resonances correspond to higher order modes. Figure 7 shows the floor at 90Hz – for mode (5,2).

Observations of the mode shapes suggest that this simple floor behaves, at frequencies below about 100Hz, like a plate with orthotropic stiffness – the joists are firmly connected to the plywood. At frequencies above 100Hz the wavelengths of the vibrations on the plywood become shorter than you might expect if the plywood was attached firmly to the joists, based on theoretical results. This might suggest that the plywood is starting to separate from the joists at regions between screws.

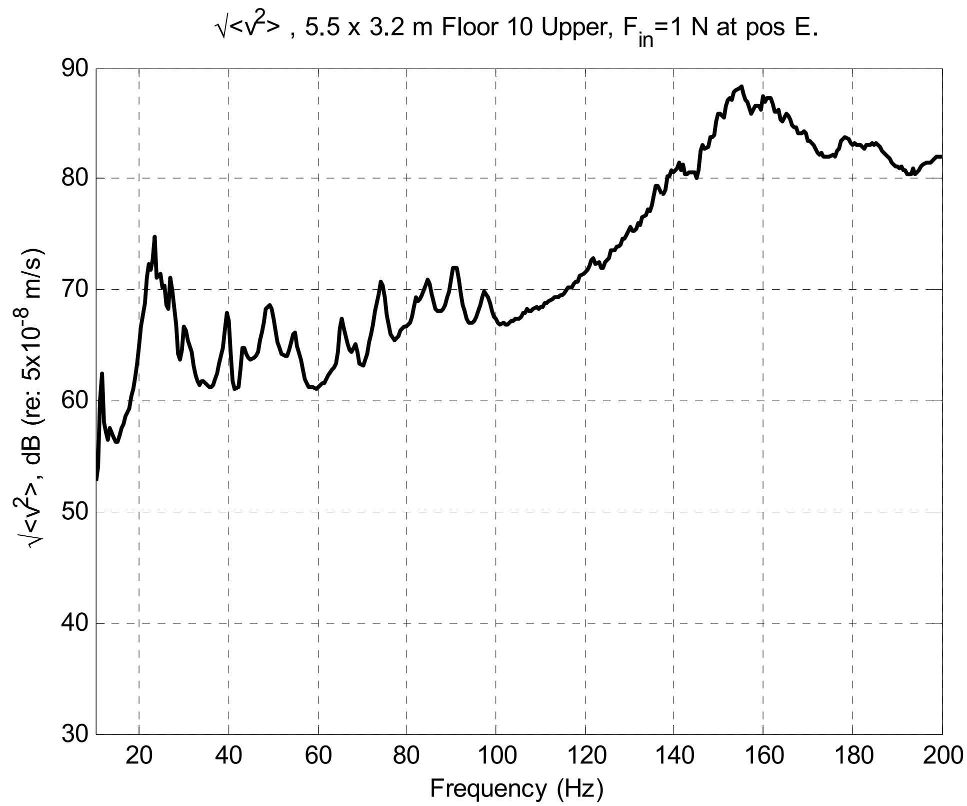

Figure 4: Averaged surface velocity plot in dB for the simple floor as a function of frequency for the upper part of the floor (there is no ceiling).

Figure 5: Underside of the simple floor.

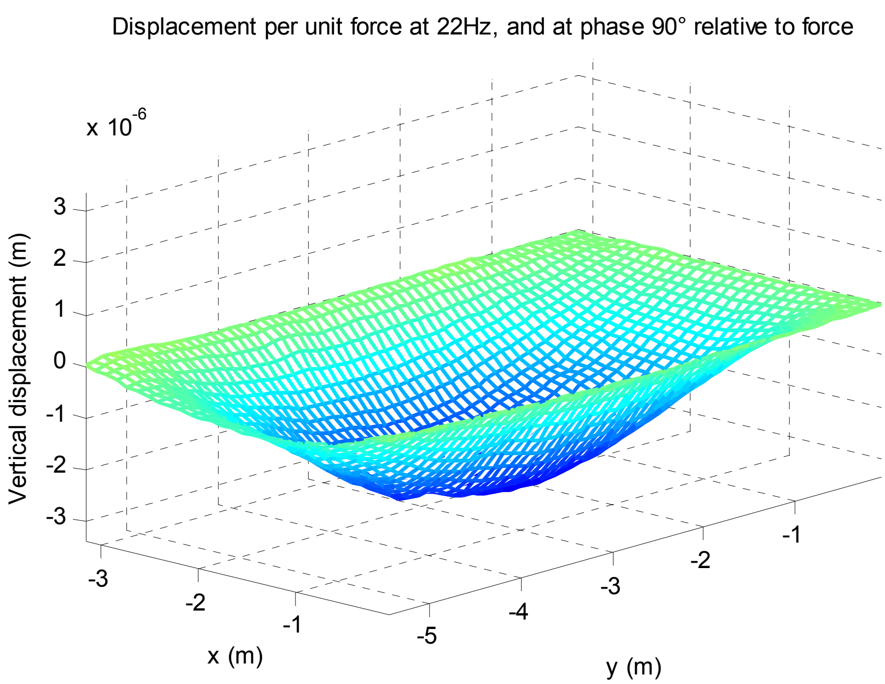

Figure 6: Illustration of the mode (1,1) on the simple floor.

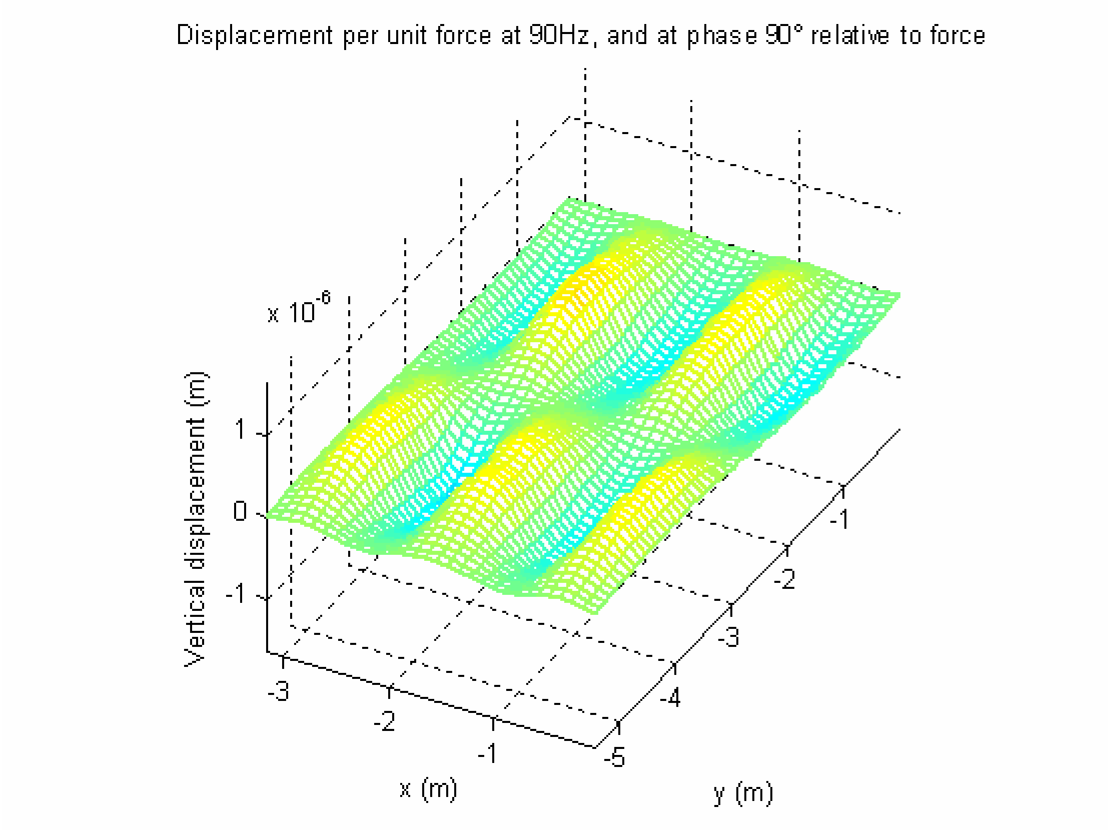

Figure 7: Illustration of mode (2,5) on the simple floor.

4.2 Simple floor with ceiling

The next floor to consider is a simple floor with a ceiling. The ceiling consists of two layers of plasterboard screwed to ceiling battens connected to the underside of the joists through resilient rubber clips (RSICs). The cavity is infilled between the joists with a 300mm depth of fibreglass batts (flow resistivity = 7200 Rayls/m). The overall cavity depth is 340mm. This floor spans 7m.

As before, Figure 9 shows the average surface velocity of the floor upper surface as a function of frequency.

It can be observed that for modes (1,1) and (1,2) at 13Hz and 20Hz respectively, the ceiling is closely coupled to the upper part of the floor. This is illustrated in Figure 10, for mode (1,2). It can also be seen that at 32Hz the ceiling starts to decouple from the floor upper. The coupling of the ceiling to the floor upper is through the air and the ceiling clips under the joists. The frequency above which this decoupling occurs is related to the mass and coupling stiffnesses of the floor/ceiling system.

In the spectral vibration response of the ceiling we see that there are frequencies where we get large peaks. This is most probably due to floor resonances coupling efficiently into ceiling resonances. This is illustrated in Figure 11.

Figure 8:View of ceiling suspension system before the plasterboard was installed.

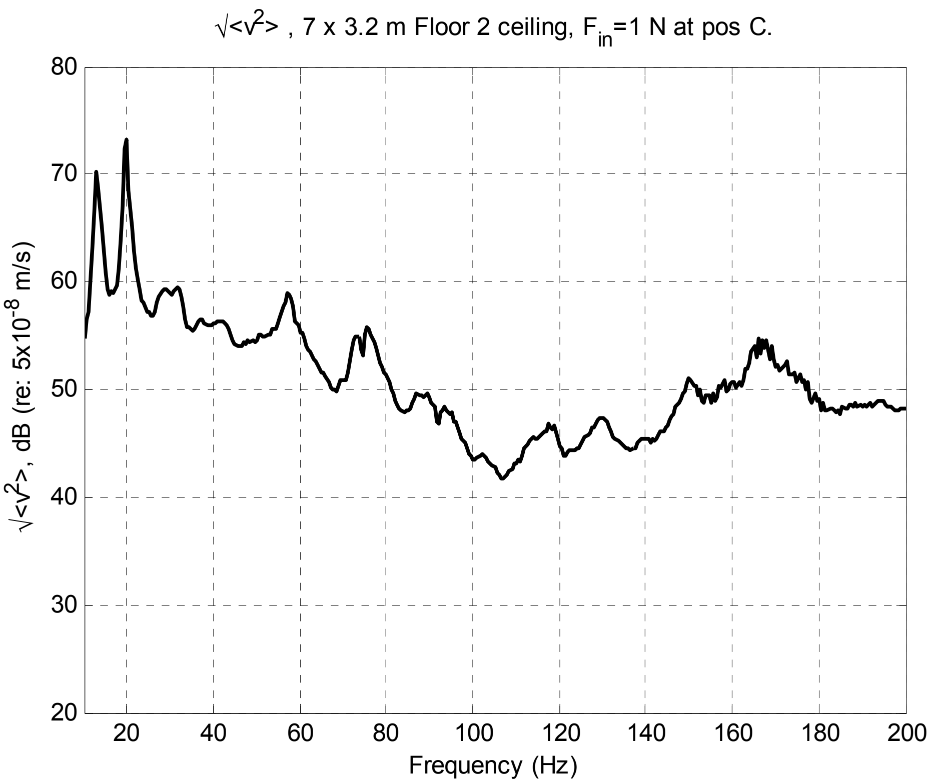

Figure 9: Averaged ceiling surface velocity plots in dB as a function of frequency, as measured by the scanning laser vibrometer.

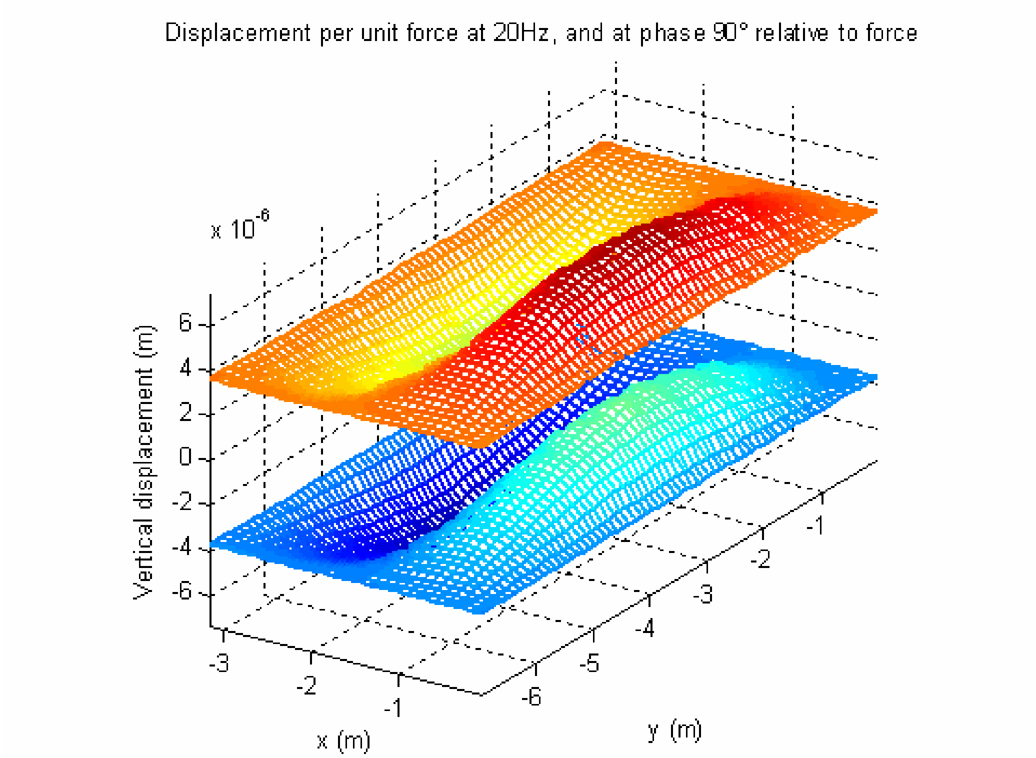

Figure 10: Illustration of vibration response of upper surface and ceiling at 20Hz on the simple floor with ceiling. This is mode (1,2). At this frequency the ceiling is clearly closely coupled to the floor upper surface.

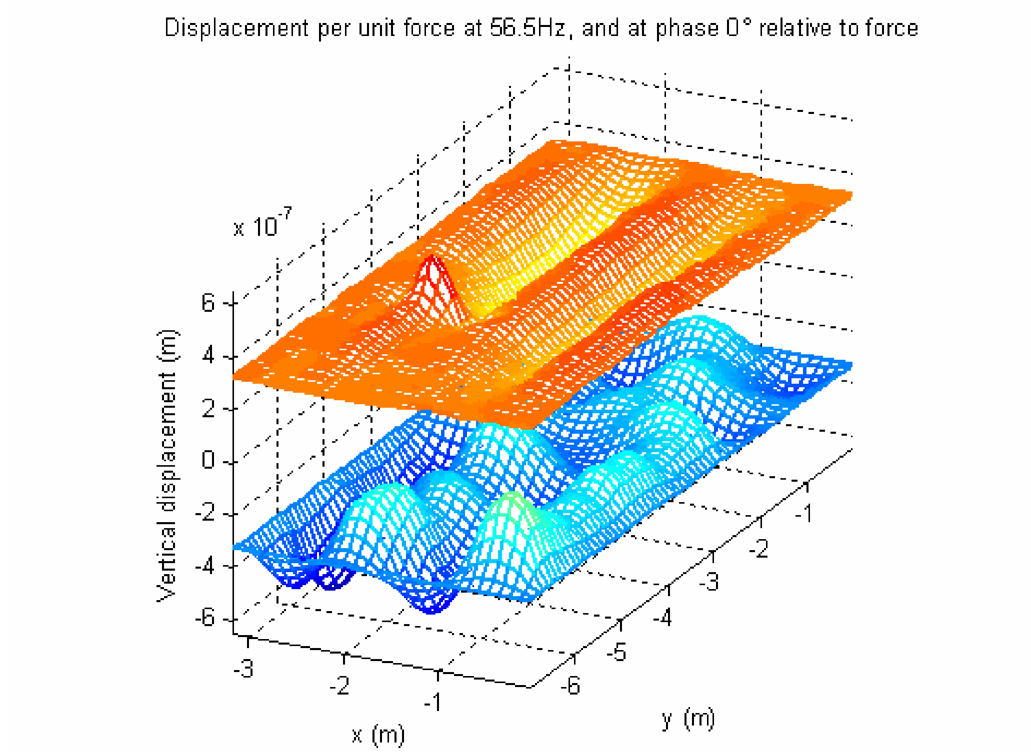

Figure 11: Illustration of vibration response of upper surface and ceiling at 56.5Hz on the simple floor with ceiling. At this frequency the ceiling is quite decoupled from the floor upper surface, and appears to be resonating. The shaker forcing point can be seen on the floor upper as a spatial peak.

5 SUMMARY

A scanning laser vibrometer system was used to provide vibration measurements on light timber-framed floors. These measurements were used to provide deeper understanding of the low-frequency performance of such floors and to help develop a theoretical model of these floors. In this paper a few results were selected to illustrate a couple of aspects of vibration propagation in light timber-framed floors.

6 ACKNOWLEDGEMENTS

The author acknowledges the support of the FWPRDC (www.fwprdc.org.au), the New Zealand Pine Manufacturers Association, CHH, CSR, Winstone Wallboards and Tenon.

7 REFERENCES

[1] H. Chung, G. Dodd, G. Emms, K. McGunnigle, G. Schmid, *Maximising impact sound resistance of timber framed floor/ceiling systems*, (FWPRDC Project PN04.2005, www.fwprdc.org.au, 2006).