REDUCTION OF LIGHT WEIGHT FLOOR VIBRATIONS THROUGH A NEW VISCOELASTIC DAMPER SOLUTION AND THROUGH ADDITION OF BUILDING STRUCTURE ELEMENTS

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ABSTRACT (Arial, Line: 25, Size: 10, word "Abstract" in capital letters)

Lightweight floor constructions often suffer from low frequency impact sounds and annoying vibrations, due to low, lightly damped, natural frequencies. In order to increase living comfort it is of great interest to find inexpensive methods that reduce floor vibrations. It is also of interest to learn about the influence of the building stages on the vibration behavior of the floors. In this paper two projects are summarized. In project 1 a lightweight steel joist floor equipped with a resilient ceiling was studied. A new damper with strategically located visco-elastic pieces was FE-modeled, manufactured and tested. In project 2 the vibration properties of a floor are tested through impacts, heel drop, walking and subjective assessments, at different building stages, i.e. freely lying floor, addition of surrounding walls, a floating floor, partition walls and furniture. Test results of project 1 show typical floor mode shapes and strong reductions of out of phase modes and some reduction of in phase modes. The results of project 2 show a clear effect of all the building structures and that especially the floating floor combined with inner walls give significant reductions of the floor vibrations.

A NEW VISCO ELASTIC DAMPER SOLUTION

Background

Lightweight floor constructions have shown an increasing interest despite their drawback in terms of high level of vibrations. The dynamic properties of the floors are such that lightly damped resonances of low frequencies are easily excited by human activities like walking running and jumping. Since humans are sensitive to such vibrations habitants often experience the floors as annoying and the problem is intensified when long span floors are subject to the tendency of more slender constructions. Steel floors seem to be specially affected as they are lighter and have less internal damping compare to wood floors, Kraus et al. [1].

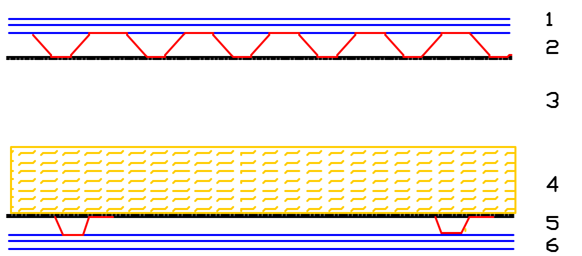
A number of researchers have reported different solutions to reduce the level of resonant vibrations. A tuned mass damper, TMD, works very well in theory as a vibration absorber and is described by Shope et al [2], Emmanuel et al. [3] and Setareh et al [4]. In addition, a modified TMD is reported as a semi-active tuned vibration absorber, Howard et al. [5]

The principal of a TMD is that the energy from the vibrating floor is transferred to a, compared to the size of the floor, small damping device in which the energy dissipates. Although the technique is capable to significantly improve the comfort of the floor it is far too sensitive. It can not handle dynamic changes of the floor that for instance occurs when the mass increases due to e.g. additional persons or furniture. Due to the described sensitivity and partly also due to that *one* mass damper can treat only *one* resonant mode, the use of tuned mass damper is not widely used. It is restricted in use as a makeshift solution in cases with severe vibrations that were underestimated in the design stage.

Other solutions have been tried like having a visco-elastic damper installed between the floor and a foundation wall, Eriksson [6], and the sophisticated active control system, Hanagan et al. [7]. For the case when a top layer of concrete is used a visco-elastic admixture can replace the water to some extend, Moiseev [8]. Most of the presented methods are expensive and complicated to use and often give not as good result as wanted indicating a need for alternative solutions.

<u>The test object</u>

The floor is originally built in a traditional way with load-bearing beams of C-profile (3) in the main direction. On top of these a 45mm profiled sheet metal (2) and two layers of plasterboard (1) are mounted. Underneath the C-profiles, a suspended ceiling consisting of resilient ceiling joists (5) and another two layer of plasterboard (6) is mounted. The floor is manufactured as prefabricated elements, each of the width 1.20m. The length can be varied but in the conducted experiments the span is 7.20m.
The described construction has potential to give severe vibrations. Heel-drop tests were performed by several people on single elements as well as on a complete floor installed in a building. The result points in the same direction; the described floor structure suffers from annoying impact vibrations of long duration, at least partially as a result of poor damping. The vibrations are worse in the case of freely lying elements compared to the situation in a real building but even in the latter case the vibrations were troublesome.



1. 13+13 mm. Plasterboard
2. 45 mm. Profiled sheet metal
3. *C*-beams, height 300-350 mm
4. 95 mm. Mineral wool
5. 35 mm. Ceiling joist c450
6. 13+15 mm. Plasterboard

Figure 1: Design of the examined floor. The prefabricated elements have a width of 1.20m.

The objective of the study was to find a method that increased the level of damping at resonance frequencies, that is uncomplicated to install, that is unsusceptible to changes in natural frequencies in the construction, and perhaps the most important, is reasonably cheap. In order to find out the dynamic characteristics of the floor in terms of natural frequencies, damping ratios, and mode shapes, a vibration measurement was performed on one single element, 7.2m, followed by a modal analysis. Heavy concrete walls about one meter high supported the floor. An electromagnetic shaker excited the floor and the response was measured with accelerometers at 11 points for the damping and 33 points for the mode shapes.
Four resonance peaks are immediately noticed, figure 4. The peaks of 8.2 and 14.2 Hz correspond to a bending mode of first order in the floor where the difference is the oscillation phase of the ceiling. A very good parallel example are the two frequencies and mode shapes that occur in a two-degree of freedom system. The peak at 11.5 Hz is explained by a torsion mode

where the ceiling and floor has equal phase. The hardly detectable peak at 21.5 Hz is a torsion mode when the ceiling is moving out of phase relative to the floor. The peak at 26.8 Hz is the bending mode of the floor of second order. The mode shapes can be seen in Figure 2.

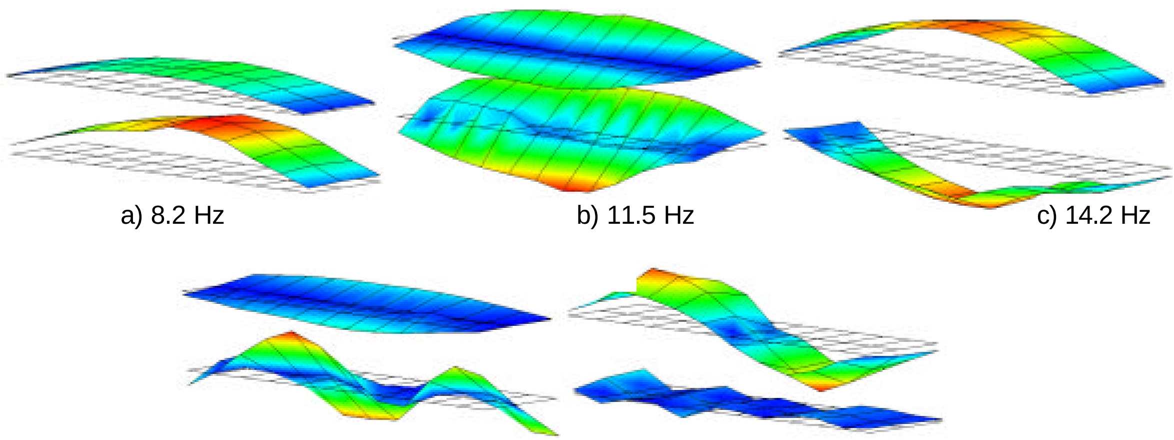


Figure 2: Mode shapes as a result of measured FRF´s in 66 points. The accelerometers are equally distributed on floor (upper) and ceiling (lower).

A new damper design

When the system is oscillating with floor and ceiling moving out of phase relative to each other, there is a considerable movement in the ceiling joists. Even when the floor and ceiling are moving completely in phase there could be a relative movement in the ceiling joist due to different amplitudes. An idea is proposed that this movement is sufficient to enable the use of visco-elastic material to increase the damping. Tests are reported in [9] Ljunggren et al.

In the experiment with the new damper, which is applied for a patent, two angle pieces were mounted beside every ceiling joist, one at each side of the floor element. The optimal material properties in terms of viscous damping coefficient and spring stiffness of the damper is found from a finite element model and the amount of visco-elastic material is designed to match the theoretical result. The arrangement is shown in Figure 5. Resulting FRF can be seen in Figure 4.

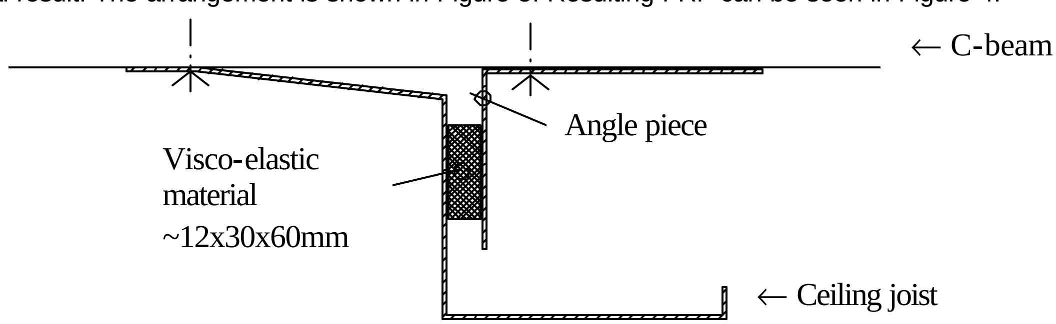


Figure 3: The visco-elastic material is mounted between an angle piece fastened to the main beam and the ceiling joist. The damping device is applied for a patent.

There are small increases in the values of natural frequencies which is explained by the fact that the visco-elastic material has slightly increased the stiffness of the floor. Regarding damping, there is a considerable change in the 14.2 Hz mode where the resonance peak is nearly eliminated and the tendency of the mode at 21.5 Hz is no longer noticeable. The effect regarding the other resonance peaks is small, even though the damping seems to be slightly higher. The results are summarized in Table 1.

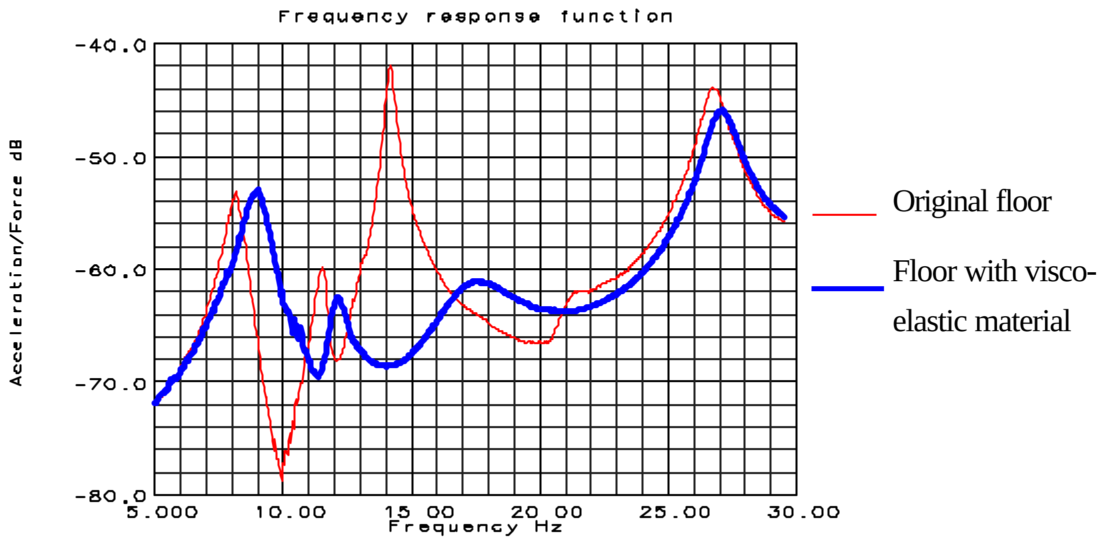


Figure 4. Comparison between measured FRF of the original floor and the floor equipped with the visco-elastic damper. The curves are average values from 11 measured points each.

Table 1: Comparison between original floor versus floor equipped with visco-elastic material.

	In phase mode		Out of phase mode		2nd order bending mode	
	F. (Hz)	ζ^a (%)	F. (Hz)	ζ^a (%)	F. (Hz)	ζ^a (%)
Original floor	8.2	3.7	14.2	1.1	26.8	1.9
Floor with visco-elastic material	9.3	5.2	≈17.6	>10	27.1	2.3

[a]Damping ratios from measurements are calculated using the half-power bandwidth method.

<u>Conclusions about the damper</u>

Without doubt the use of visco-elastic material connected to the ceiling joists substantially increases the damping, and thereby reduces the resonant vibrations, in a steel joist floor of the type used in this experiment. However, the method is primarily useful for damping resonance peaks corresponding to mode shapes where the floor and ceiling are moving out of phase. The other resonant modes were less affected but still increments in damping were noticed. Compared to the use of tuned mass dampers, there is a great advantage in the visco-elastic method (VEM) applied to floors equipped with a resilient ceiling, in respect of sensitivity. While a TMD must be tuned exactly to a proper frequency the VEM works in a broader frequency range. Further more, *one* TMD can only damp *one* mode shape. If damping of several mode shapes is necessary the arrangement gets very complex. In similarity the VEM is working optimally only for a specific type of mode shapes. Nevertheless it is a very cheap method that very well can be included in the manufacturing from the very beginning. The visco-elastic method looks promising so far, although a better result for mode shapes that are now less affected in the experiment is desirable.

THE INFLUENCE OF BUILDING STRUCTURE ELEMENTS ON THE DYNAMIC BEHAVIOUR

The objective of this investigation was to experimentally study the light weight steel floor structure dynamic properties at different construction phases. The test floor is a 6m span lightweight steel floor, with the area 6x18m^2. All the tests and measurements were conducted at the following construction phases:

1. Freely lying floor without any walls
2. With surrounding wall loading the edges
3. With surrounding wall and partition walls
4. With surrounding wall, partition walls and floating floor
5. With surrounding wall, partition walls, floating floor and furniture

The tested light weight steel floor comprised: parquet, 30 mm mineral wool, 250/2.5 C-profile, mineral wool, ceiling suspension, gypsum board and IPE-girders.

Mobilty and damping was measured with sledge-hammer excitation. Heel drop excitation was tested from phase 3 to phase 5. Walking indused vibrations were measured. Five accelerometers were distributed close to the walking path, figure 2, and another two were placed at distance from the walking path. Generally, human walking step frequency can be treated as 2 Hz and its harmonics.

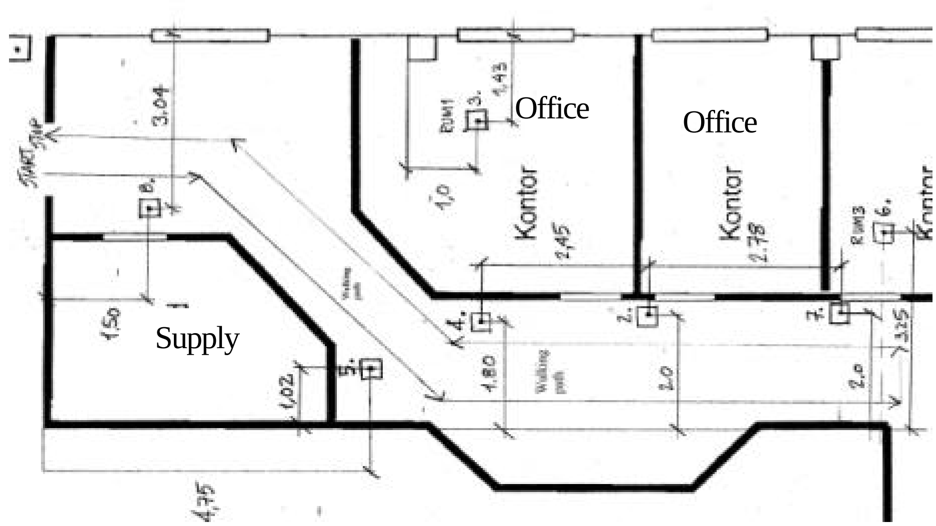


Figure 5. Walking path and the distribution of the accelerometers.

Subjective evaluations of the walking induced vibrations were also conducted. Ten persons participated and made assessments both of a sitting/exposed situation and a walking/excitation situation. A questionnaire survey was utilized for subjective assessment of floor vibrations for 2 of the 5 construction phases (*without wall* and *with floating floor and partition walls*). Questions including ***1)*** perception of the floor vibrations for the walker, rating on 5-point scale[1] ***2)*** perception of the floor vibration when somebody else is walking on the floor, rating on 5-point scale [2] ***3)*** how will the subjects rate the floor if the floor were in his home (acceptable vs. not acceptable).

<u>Results of walking induced vibrations</u>

Floor responses to walking induced vibrations are shown in figure 6. Generally speaking, phase 4 has lowest vibration level in all frequencies above 9Hz (the 1st resonance frequency), which implies that the final construction with floating floor and partition walls has a good effect on the vibrations. As expected, the bare floor has the highest vibrations. A comparison between phase 4 and 5 shows that the furniture gives lower vibration levels below 8 Hz, but somewhat surprising, higher vibration levels above 25 Hz. This will be further investigated.

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[1] (5-perfect, 4-acceptable, 3-barely acceptable, 2-not acceptable, 1-really unpleasant)
[2] (5-not noticeable, 4-noticeable, 3-little disturbing, 2-clearly disturbing, 1-annoying)

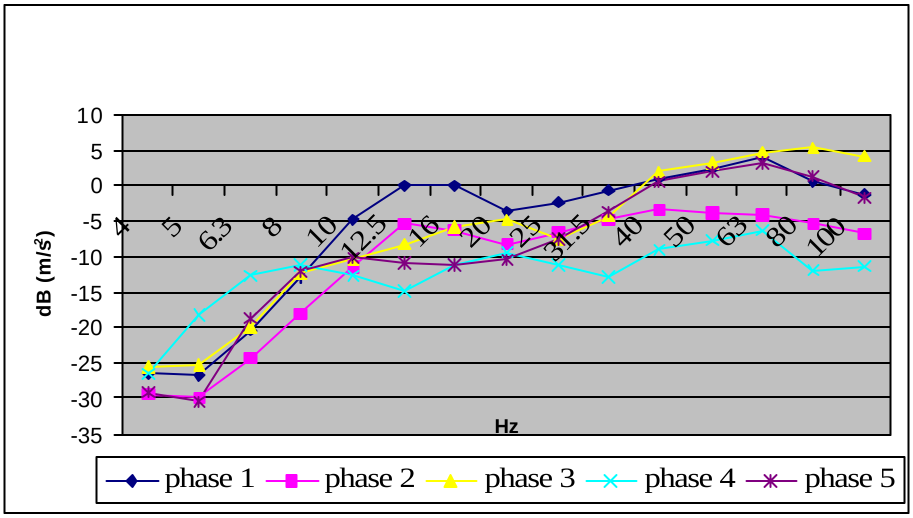

Figure 6. Acceleration plots of walking induced vibrations for different construction phases.

Results of heel drop tests

The heel drop test mainly verifies that the floating floor acts as a good low-pass filter for vibration insulation and that the placing of furniture also affects as a low-pass filter.

Results of subjective evaluations

Statistical analyses were conducted on the data from the subjective evaluation tests. Mann-Whitney U-test for association showed no significant differences of the vibration perception rating ($U_{obs}=29>U_{crit}=15,\ p>0.05$) regarding that subjects won't feel any difference in annoyance by the floor vibrations when he/she is walking around. There were significant differences of the vibration perception rating ($U_{obs}=13<U_{crit}=15,\ p<0.05$) of the two construction phases (freely lying floor ⇔ with floating floor and partition walls), subjects accepted the latter construction and rejected the lying floor. Chi-square test showed that there was highly significant differences ($\chi^2 = 8.93$, *p= 0.00281*) of people's attitude towards floor vibration at home. For the freely lying floor, there was only 10% acceptance, but for the floor with partition walls, the acceptance was 78%. In other words the bare floor is absolutely not acceptable for dwelling.

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