Effect of flexible supports on vibration performance of timber floors

Kirsi Jarnerö
SP Wood Technology, SP Technical Research Institute of Sweden, Växjö , Sweden
Åsa Bolmsvik
Linnaeus University, School of Engineering, Växjö, Sweden
Anders Brandt
University of Southern Denmark, Institute of Technology and Innovation, Odense, Denmark
Anders Olsson
Linnaeus University, School of Engineering, Växjö, Sweden

Summary

In residential multi-storey buildings of timber it is of great importance to reduce the flanking transmission of noise. Some building systems do this by installing a vibration-damping elastic interlayer, Sylomer® or Sylodyn®, in the junction between the support and the floor structure. This interlayer also improves the floor vibration performance by adding damping to the structure. In the present work the vibration performance of a floor with such interlayers has been investigated both in laboratory and field tests. A prefabricated timber floor element was tested in laboratory on rigid supports and on supports with four different types of interlayers. The results are compared with *in situ* tests on a copy of the same floor element. The effect on vibration performance i.e. frequencies, damping ratio and mode shapes is studied. A comparison of the *in situ* test and the test with elastic interlayer in laboratory shows that the damping *in situ* is approximately three times higher than on a single floor element in the lab. This indicates that the damping *in situ* is affected be the surrounding building structure. The achieved damping ratio is highly dependent on the mode shapes. Mode shapes that have high mode shape coefficients along the edges where the interlayer material is located, result in higher modal damping ratios. The impulse velocity response, that is used to evaluate the vibration performance and rate experienced annoyance in the design of wooden joist floors, seems to be reduced when adding elastic layers at the supports.

PACS no. 43.40.At, 43.55.Vj

1. Introduction

In the present work the vibration performance of floors with flexible support has been investigated both in laboratory and field tests. Different elastic interlayers, Sylodyn® and Sylomer®, between the support and the floor structure have been tested. These kind of interlayers are used to reduce the flanking transmission of noise in timber structures and it also adds damping to the structure, improving vibration performance.

2. Test setup and measurements

2.1. Tested floor

The tests were performed on a single floor element, 1.5 m wide and 5.1 m long, from a building system commonly used on the market in Sweden. The load carrying part of the floor consists of a 73 mm thick three-layer cross-laminated timber (CLT) board on top and four glulam beams with center distance 460 mm underneath. The beams consist of C40 glulam webs and flanges, with dimensions 42×220 mm^2 and 56×180 mm^2 respectively. The beams are both glued and screwed to the CLT. Only the load carrying part of the floor element was tested i.e. it had no ceiling underneath and no mineral wool was installed between the load bearing glulam beams.

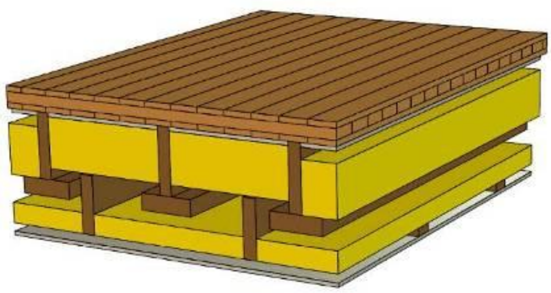


Figure 1. Basic drawing scetch of a finnished floor structure including separate ceiling.

During shipment of the floor element the ceiling is attached to the upper load carrying part, but as it has been installed the ceiling is detached and lowered into place on the supporting walls underneath. In finished buildings it is separated from the load carrying part and is self-supporting on the walls in the underlying room and has no contact with the upper load carrying part.

To reduce the flanking transmission in finished buildings interlayers of vibration-damping Sylodyn® and Sylomer® are placed between the supporting walls and the CLT board of the floor. The Sylodyn® and Sylomer® interlayers are polyurethane (PUR) elastomers and their performance is adjusted to the expected final static loading in the finished building. Thus interlayers with decreasing static load capacity are used the higher in the building they are installed. In the static range of use the relationship between load and deflection of the material is mainly linear. After the static load range the relation between load and deflection changes and the material becomes "softer" and the deflections due to additional static and dynamic loads increases. This load range is included in the dynamic range of use and allows, according to the supplier [1] for effective vibration isolation. When the dynamic range limit is exceeded the material becomes stiffer again with reduced vibration isolation efficiency as result.

The interlayers used in the investigated building structure have a cross-sectional dimension of 25×40 mm^2 and are installed in a 15 mm deep and 40 mm wide routed groove on top of the supporting walls. The groove in the present tests was accomplished by two fillets of laminated veneer lumber LVL screwed to the top of the supporting beam as shown in Figure 2.

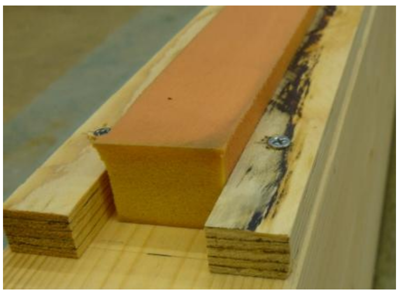


Figure 2. A Sylomer® interlayer installed between LVL fillets.

2.2. Testing

In the present work the floor was tested with simply supported support conditions, laid up on two sides on glulam beams with dimensions 90×315 mm^2, that were underpinned with concrete on the floor as shown in Figure 3. The ends of the floor elements was placed on the beams resting only on the CLT board, meaning that the glulam beams are cut off at the ends of an element and not laid up on the supports.

Figure 3. Simply supported support conditions in laboratory tests, floor placed on glulam beam in left picture and on steel beam in the right picture.

The tests were performed without and with different types of vibration-damping interlayers installed on the supports as follows:

- Floating with no fastening to the supporting beams.
- Screwed to the supporting beam with 5×90 wood screws with center distance 250 mm.
- Resting, with no fastening, on four different types of interlayers as listed in Table 1.

Table 1. Properties of of Sylodyn® and Sylomer® interlayers.

Type	*Color*	*Static range of use* (N/mm^2)	*Ratio of utilization* (%)
Sylomer SR28	Blue	0.028	159
Sylomer SR42	Pink	0.042	102
Sylomer SR55	Green	0.055	84
Sylodyn NF	Purple	1.500	5

The mass of the floor element is 511 kg which yields a static load of 41.2 N/mm^2 at the supports. In Table 1 the ratio of utilization of the tested types of interlayers are presented. The type of

Sylomer® best adjusted to the current static load is the Sylomer® SR55, colored green.

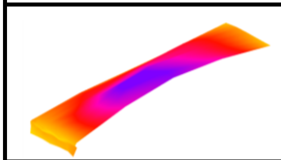
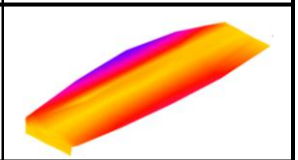
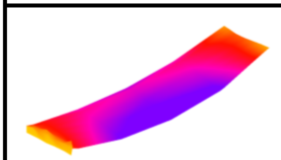
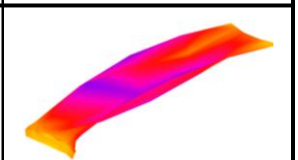
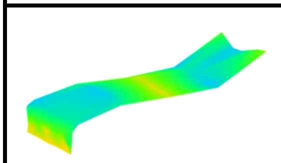
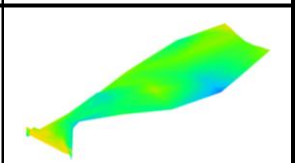
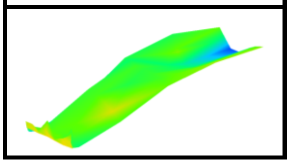
The same floor element has been tested before in laboratory and also a copy of it has been tested *in situ* when installed into a building. These tests are presented as a whole in [2]. The previous laboratory test was also performed with simply supported support conditions, but the supporting beams were then steel beams with wooden beams placed on top as shown in Figure 3. There was also a 3 mm thick interlayer of EPDM rubber installed between the CLT board and the supporting glulam beam. The test was performed with the floor floating with no attachment to the supports. The in situ test of the floor element was performed as the floor was laid up on and screwed to the walls underneath, but not yet fastened to the adjacent floor elements. During testing there was a 5-10 mm wide gap to the adjacent elements. The walls on the same storey were not installed so there was no clamping of the floor at the supports and the ceiling in the room below was lowered into place on the supporting walls. As the test was performed on the third floor of totally eight the installed Sylodyn® interlayers used on top of the supporting walls were of a high load bearing quality, Sylodyn® NF, at one of the supports and even of stiffer quality at the other. In the present work, for comparison with the previous tests, the floor element in laboratory was tested resting on the Sylodyn® NF interlayer.

In the laboratory tests the floor element was excited with an electromagnetic shaker, LDS V406-PA500, suspended from an overhead crane. In the *in situ* tests the shaker was suspended from a tripod standing on the tested floor. The floor response was measured with Kistler 8772A 5T and 50T accelerometers in vertical direction on the floor surface. The excitation of the floor was performed with a pseudo random signal and the force was measured with a Kistler 9301B force transducer attached to the floor with a wood screw and to the shaker by a threaded stinger. The excitation point was located 0.68 m from the centerline along the length, between two rows of response measurement points, and 0.23 m from the centerline, between two beams, along the width. The data acquisition was performed with a 30 channel LMS SCADAS Lab FFT analyzer. Each saved measurement run was averaged from 20 measured blocks of data.

3. Analysis

The extraction of modal parameters i.e. resonance frequencies, damping ratios and mode shapes has been performed using LMS TestLab software by means of the polymax modal parameter estimation method. The analysis was divided into steps, beginning with an analysis of the entire measured frequency span of 100 Hz and then followed by several steps with narrower frequency bands to ensure that all modes were found. The selection of poles was done automatically by the software, but when narrowing the analyzed frequency band an assessment of what poles to include had to be done manually. The mode shapes were extracted by a least-squares frequency-domain LSFD method, and frequency response functions (FRFs) were then synthesized and compared with the corresponding measured ones. The data from earlier performed measurements in laboratory and in situ were reanalyzed along with the new data. The aim has been for the different test setups to find the same modes of vibration. The modes from each of the setups, and from the previous tests, were matched visually, and the modes were then sorted as presented in Table 2.

Table 2. Compared mode shapes.

Mode 1	*Mode 2*
	
Mode 3	*Mode 4*
	
Mode 5	*Mode 6*
	
Mode7	
	

The numbering of modes presented in the table does not necessarily correspond to the analyzed mode order of the test setups, but is a mode shape reference number to simplify the presentation and comparison of results.

To make an assessment about the effect of different interlayers on the floor vibration performance the impulse velocity response was calculated from the driving point mobility of each laboratory setup. The impulse velocity response is the peak velocity response that would be excited in the structure by a unit impulse of 1 Ns. In Figure 4 the driving point acceleration of the presently performed measurements are presented.

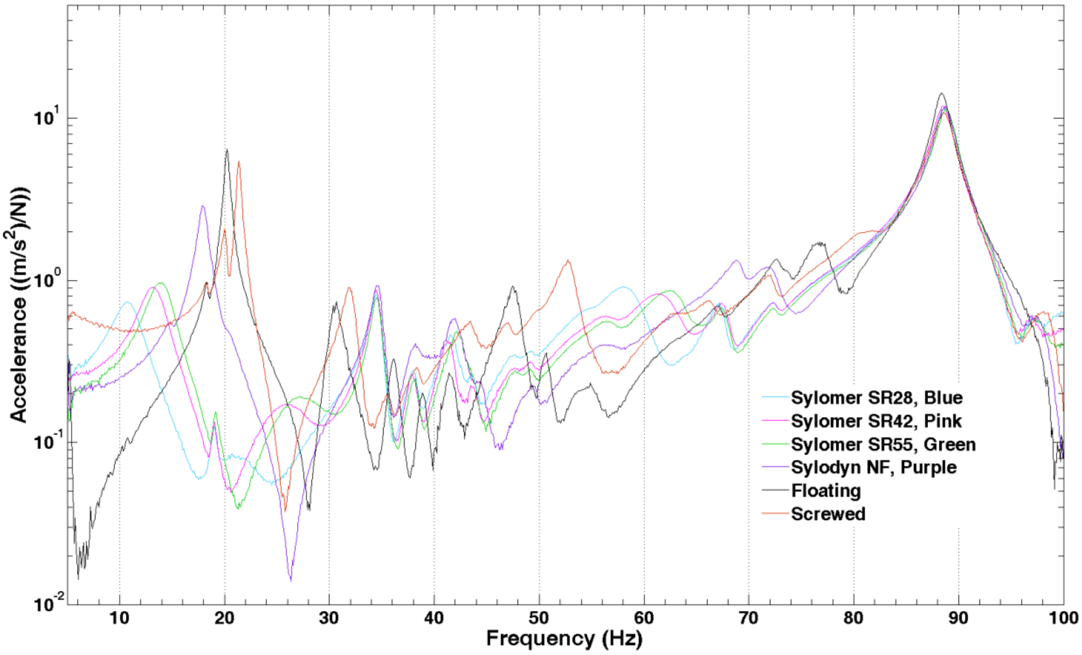


Figure 4. Driving point accelerances of performed laboratory tests.

4. Results and discussion

It is, when looking at the driving point accelerances presented in Figure 4, clear that the vibration-damping interlayers do affect the vibration performance of the floor. The resonance frequencies are moved and more damping is added into the structure.

In Table 3 the extracted resonance frequencies are presented and the corresponding damping ratios in Table 4. To simplify comparison the frequencies are also plotted in Figure 5 and the damping ratios in Figure 6.

Table 3. Extracted resonance frequencies.

Mode (No)	*Blue SR28* (Hz)	*Pink SR42* (Hz)	*Green SR55* (Hz)	*Purple NF* (Hz)	*Floating* (Hz)	*Screwed* (Hz)	*OldLab* (Hz)	*InSitu* (Hz)
1	6.2	6.4	6.2	8.2	5.2	12.8	-	-
2	-	13.1	13.6	20.3	18.5	19.5	18.8	17.1
3	11.1	13.8	14.3	18.0	20.2	21.0	20.4	19.1
4	34.5	34.5	34.6	34.6	38.9	36.8	37.7	28.9
5	21.5	26.9	28.1	39.1	47.4	52.7	44.7	41.6
6	54.9	56.5	56.9	69.1	50.5	58.7	67.6	54.8
7	59.0	62.1	63.0	72.3	77.1	81.6	78.9	88.7

Table 4. Extracted damping ratios.

Mode (No)	*Blue SR28* (%)	*Pink SR42* (%)	*Green SR55* (%)	*Purple NF* (%)	*Floating* (%)	*Screwed* (%)	*OldLab* (%)	*InSitu* (%)
1	6.5	1.6	3.4	2.2	0.4	2.6	-	-
2	-	8.6	6.9	2.5	0.8	1.4	1.5	4.4
3	12.2	3.5	6.8	2.5	1.2	1.7	1.4	6.2
4	1.4	1.4	1.3	1.2	1.0	1.2	1.4	4.2
5	14.7	6.3	6.9	3.3	1.7	1.9	1.7	6.1
6	2.6	2.4	2.3	1.2	0.8	1.6	1.3	2.2
7	3.7	3.9	3.7	2.6	1.6	1.3	1.7	4.9

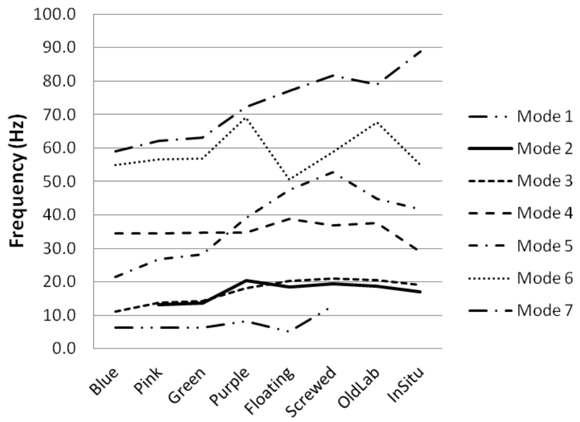


Figure 5. Frequencies plotted in mode series

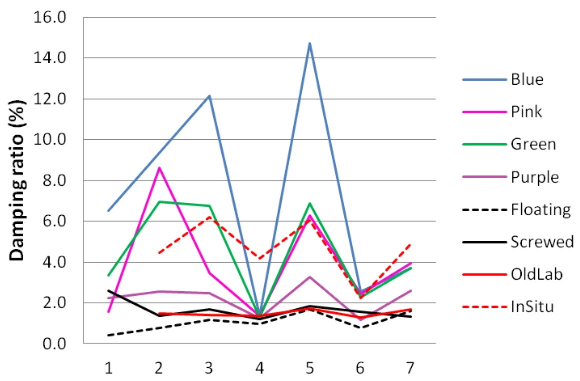


Figure 6. Damping ratios for performed tests.

When comparing the damping ratios plotted in Figure 6 it is seen that the damping is highly dependent on the type of interlayer, or more precisely the ratio of utilization. The blue, SR 28 Sylomer® that is loaded above the static load limit, 159 % static load utilization, shows very high values of damping ratio for mode 3 and 5, 12.2% and 14.7% respectively. This is explained by the "softer" behavior and higher vibration isolation ability that can be expected in the dynamic range above the static load limit. The explanation for the high values in these modes is probably that they have high mode shape coefficients along the edges, and thus excite the supports to a larger extent, with larger energy dissipation as result. The same phenomenon is observed for the other two types of interlayers, pink SR42 and green SR55. The damping ratios are lower, about 6%, which may be explained by the lower ratio of utilization. For the Sylodyn® NF, that was tested for comparison with the tests performed earlier *in situ*, the damping values are somewhat increased for mode 3 and mode 5 when compared with the floating and screwed test setups. An increased level from 0.8 to 1.3% and from 1.4 to 1.6% damping is achieved for the mode 3 and mode 5 respectively. The results for the other modes are not consistent, but shows both lower and higher values than for the setups with no interlayer. The damping ratio values of the *in situ* test follow the same pattern of higher and lower values of damping as the tests performed in laboratory, both the earlier and present ones. The difference is that the damping ratio level is much higher than for the test performed in laboratory, the level is increased with amounts from 0.7 to 5 % damping ratio. The damping ratio of mode 4 is increased with an amount of 3 % damping more than for all of the other setups. This must be an indication that there are other reasons to the increased damping values *in situ* than only the interlayers at the supports, i.e. that *in situ*, the floor element is affected by surrounding building parts adding damping. There might have been connection points to the adjacent floor elements and/or to the ceiling below. The mineral wool inside the load bearing part may add some damping just as the supporting walls that most likely are flexible to some extent. Also the fastening of the floor with screws to the supporting walls contributes to added damping.

In multi storey timber frame buildings an elastic interlayer at the support will probably be of a stiffer type of material due to expected high final static loads. As the choice of interlayer is adjusted to perform in the static loading range it means that the "softer" behavior in the upper dynamic range will probably not be utilized by normal loading i.e. the higher damping values that was seen in the laboratory tests will not occur in a real building. On the other hand it may be concluded from the performed tests that there still is a contribution to floor vibration damping from a stiff interlayer, as Sylodyn® NF. The damping ratio is increased with the amount of 1% damping between the laboratory test with the Sylodyn® NF interlayer and the screwed and the floating floor element tests.

When studying both the plotted frequencies and damping ratios an interesting observation is that mode 4, which is a first order bending mode across both the length and the width of the floor, changes very little when the type of interlayer is changed. If just looking at the frequencies it seems as if the interlayers lowers the frequencies compared with tests with no interlayers. The effect is clearest for the three Sylomer® interlayers, blue SR28, pink SR42 and green SR55. In these three test setups the mode shape sequence for modes 2 and 3 and also for modes 4 and 5 seems to be shifted between themselves. For the blue SR28 Sylomer®, mode number 2 to is lacking, as it was not possible to extract it and this is probably due to the very soft behavior of the supports. There are no results for mode 1 for the earlier performed laboratory and for the *in situ* test. This is due to the fact that the mode seems to be dependent on the present support condition. The glulam beam support introduces a low frequency mode to the setup. The impulse velocity response together with the first natural frequency and damping ratio of the floor are used to evaluate the vibration performance and rate experienced annoyance in the design of wooden joist floors. The calculated impulse velocity response of all the present laboratory tests is presented in Table 5.

There seems to be a clear correlation between the impulse velocity response and the use of different interlayers and the use of no interlayers at all. For the "soft" SR28 type of interlayer the difference to the stiffer ones are clear. The small difference in stiffness between the SR42 and SR55 seems not to be enough to have any obvious impact on the impulse velocity response. Screwing the floor to the beams, results in the highest impulse velocity. These results indicate that the impulse velocity response is reduced by using interlayers.

Table 5. Impulse velocity response for the present laboratory tests.

Impulse velocity response ((m/s^2)/Ns))	
Blue, SR28	0.237
Pink, SR42	0.268
Green, SR55	0.264
Purple, NF	0.343
Floating	0.395
Screwed	0.403

5. Conclusions

The following conclusions may be drawn from the present investigation:

- A comparison of the *in situ* test and the test with elastic interlayer Sylodyn® in laboratory shows that *in situ* damping is much (3 times) higher than the damping in the lab, which suggests the floor *in situ* is affected by the surrounding structure.
- The obtained damping ratio of the various modes is highly dependent on the mode shape. Mode shapes that have high mode shape coefficients along the edges result in higher modal damping ratios, which can be explained by the larger energy dissipation in the interlayers caused by the larger displacement.
- The impulse velocity response is reduced by adding elastic layers at the supports.

References

[1] Getzner Werkstoffe GmbH: Sylomer; Material properties and vibration isolation - Technical information

[2] K. Jarnerö, A. Brandt, A. Olsson: Vibration properties of a timber floor assessed in laboratory and during building construction, Proc of Internoise 2010, June 13-16, Lisbon, Portugal