



Cracow University of Technology
Faculty of Civil Engineering
Building Vibration Laboratory

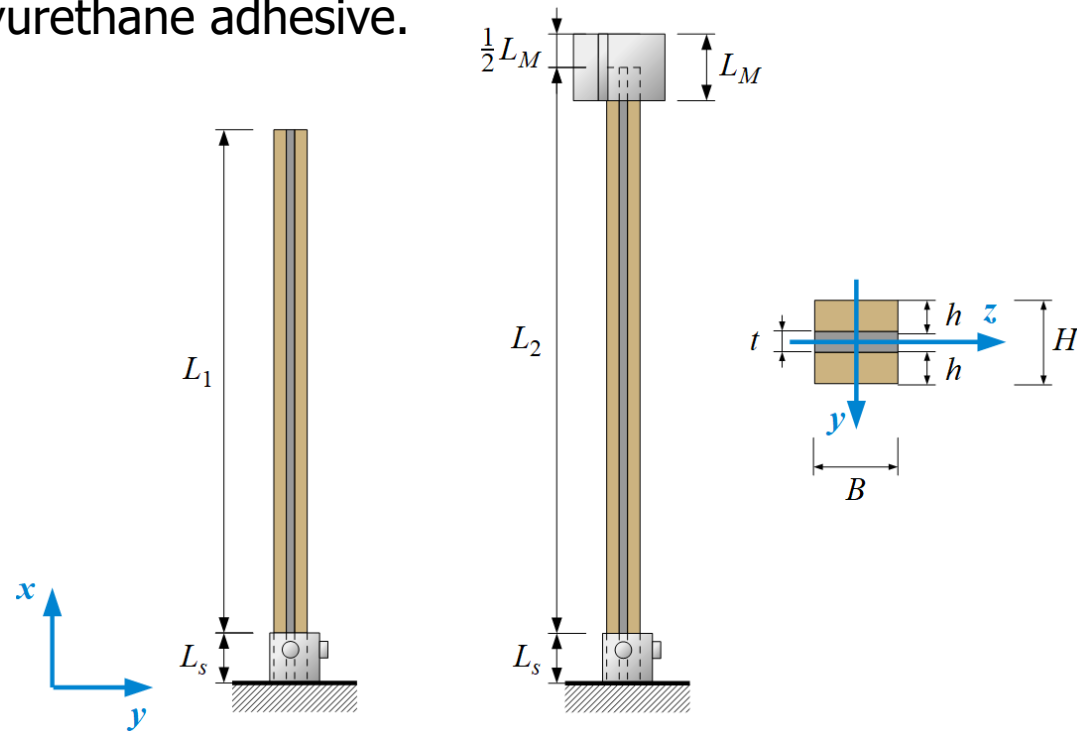
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Determination of dynamic characteristics of timber elements with PU adhesives under small and large strains

Corvallis 2025

Materials

The investigated beams are composed of two beech wood lamellas that are bonded using a flexible F&R polyurethane adhesive.



$$L_1 + L_s = 1560 \text{ mm}$$

$$B = 50 \text{ mm}$$

$$L_s = 50 \text{ mm}$$

$$H = 50 \text{ mm}$$

Materials

Dimensions of cross-sections of composite beams.

Specimen type	Height of wooden lamella h [mm]	Thickness of the adhesive layer t [mm]
Specimen type I	24	2
Specimen type I	20	10
Specimen type I	17.5	15
Specimen type I	15	20

Additionally solid wood reference beams with square cross-section 50 mm × 50 mm have also been investigated in order to estimate the dynamic Young's modulus of the wood.

Test schedule

Without additional mass

Beam excitation before long-term forcing

- Modal hammer impact excitation
- Manual deflecting
- Sweep excitation (100%, 150%, 200%)
- Earthquake ElCentro excitation

Long-term forcing in resonant frequency (10 min)

Re-excitation to check frequency and damping change

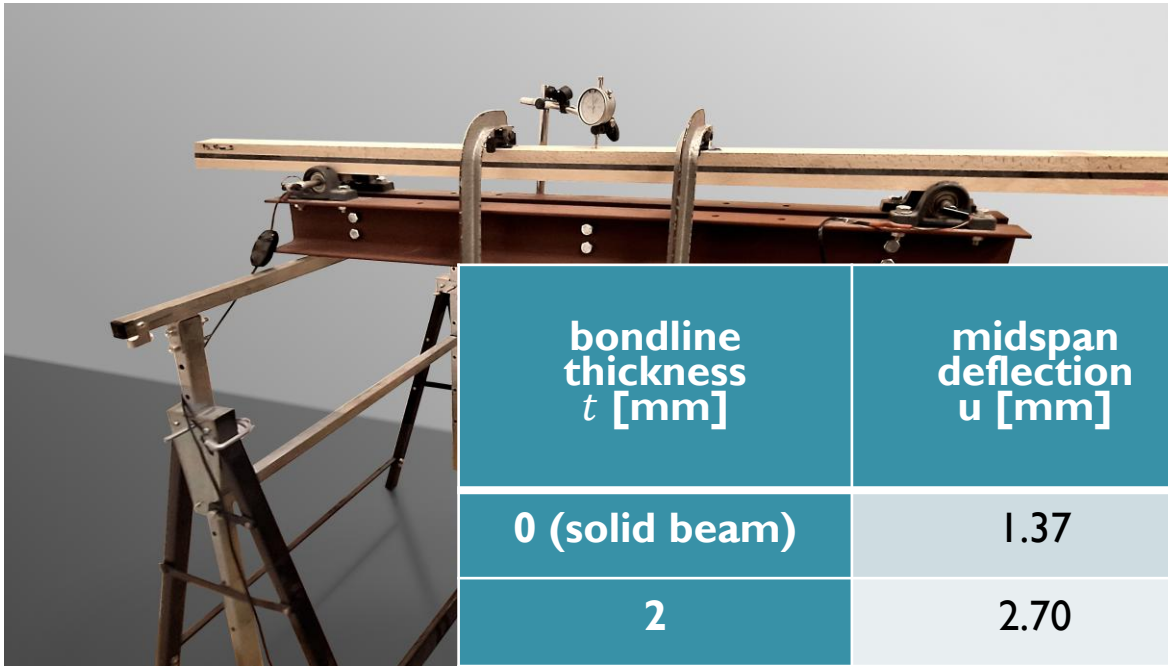
- Modal hammer impact excitation
- Manual deflecting
- Sweep excitation(100%, 150%, 200%)
- Earthquake ElCentro excitation

With additional mass ~6 kg

Test repeated previously

Materials

Flexural stiffness of composite beams was investigated in a static four-point bending test. The distance between supports was $L_s = 1\text{m}$. Two point loads of 21 kg each were attached at 1/3 and 2/3 of the span length.



$$\rho_w = 695 \frac{\text{kg}}{\text{m}^3}$$
$$E_{w,L} = 12.91\text{GPa}$$

bondline thickness t [mm]	midspan deflection u [mm]	flexural stiffness EI [Nm^2]
0 (solid beam)	1.37	5337.29
2	2.70	2708.18
10	2.48	2948.42
15	1.92	3808.38
20	1.56	4687.23

Laboratory setup

QuakeLogic Bi-Axial TDG Shake Table

- Closed-Loop PID Control
- 750x750 mm Table Size
- Up to 100 kgf payload (@ ± 1 g)
- Up to 3g
- ± 100 mm Stroke
- Operational Frequency up to 30 Hz

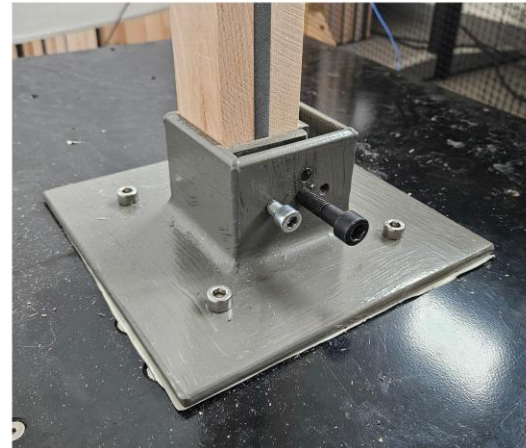
PCB Piezotronics 356A16

- Sensitivity 100 mV/g
- Measurement Range ± 50 g pk
- Frequency Range 0.5 to 5000 Hz
- Resolution 0.0001 g rms

a)

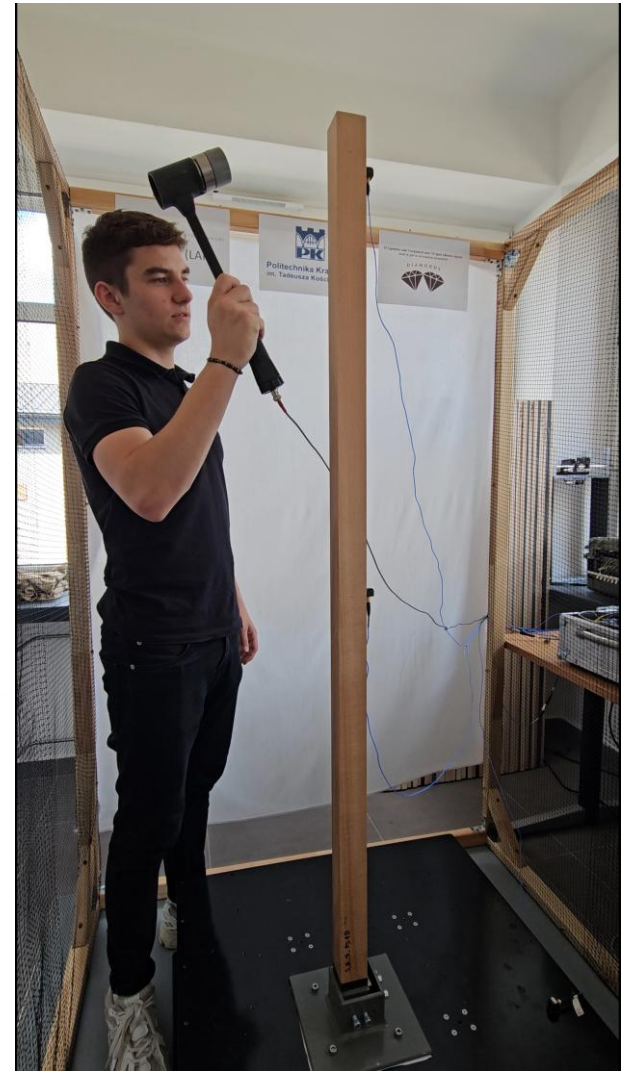
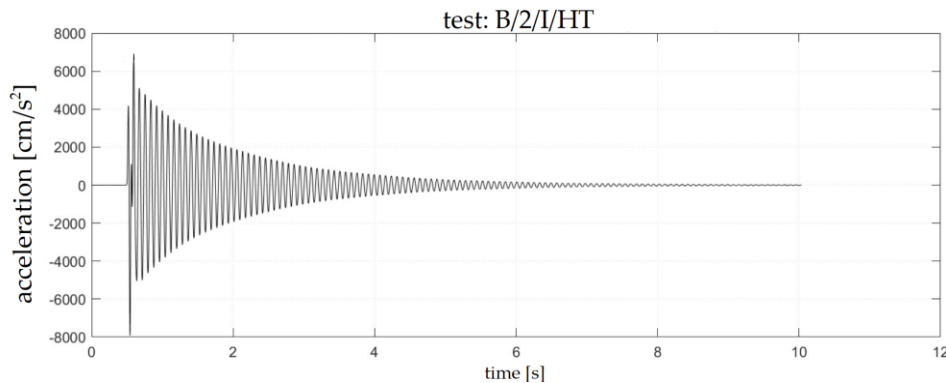
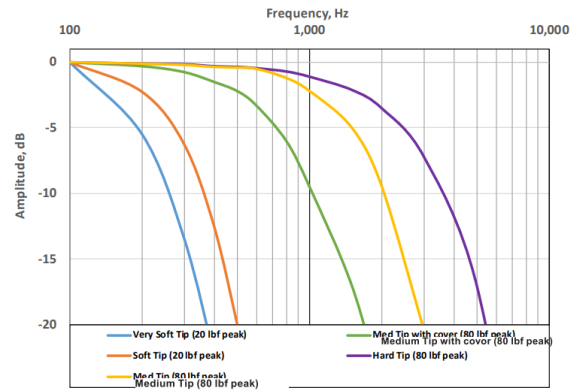


b)



Testing procedures

Impact tests were carried out with the use of 086D20 type modal hammer manufactured by PCB Piezotronics.



Three types of impact load were employed

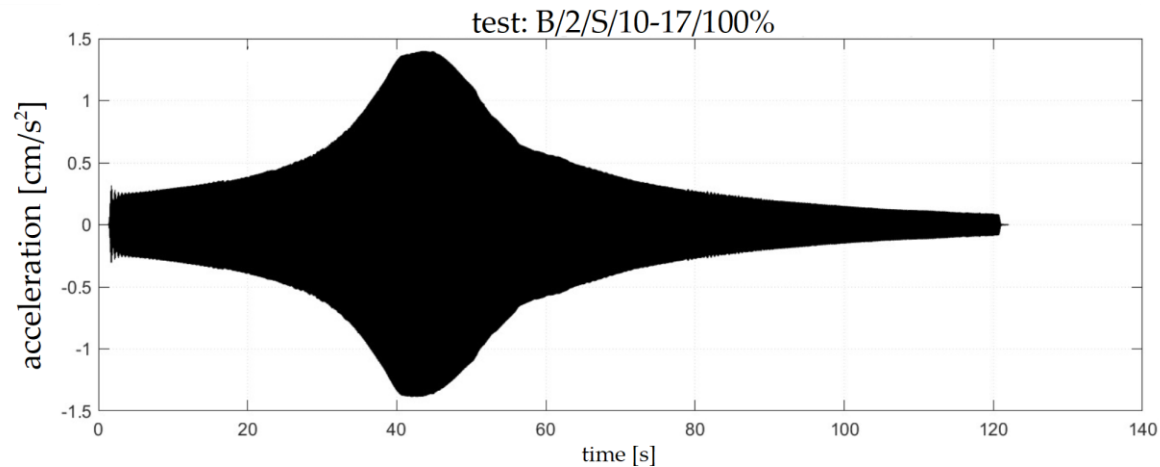
- impact hammer hitting the top of the cantilever
- impact hammer hitting the middle of the cantilever
- manual deflecting of the cantilever top.

Testing procedures

Number of 960 tests were performed.

Sweep loads were performed in three ranges of frequencies:

- 2-6 Hz for determining beams with attached mass
- 10-17 Hz for adhesive layers of thickness 2 mm and 10 mm
- 8-12 Hz for adhesive layers of thickness 15 mm and 20 mm

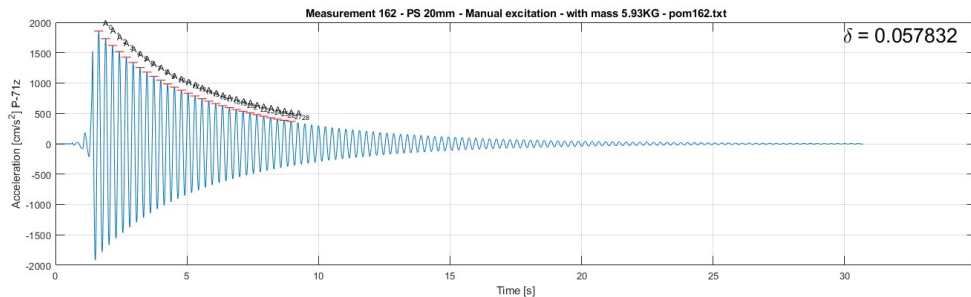
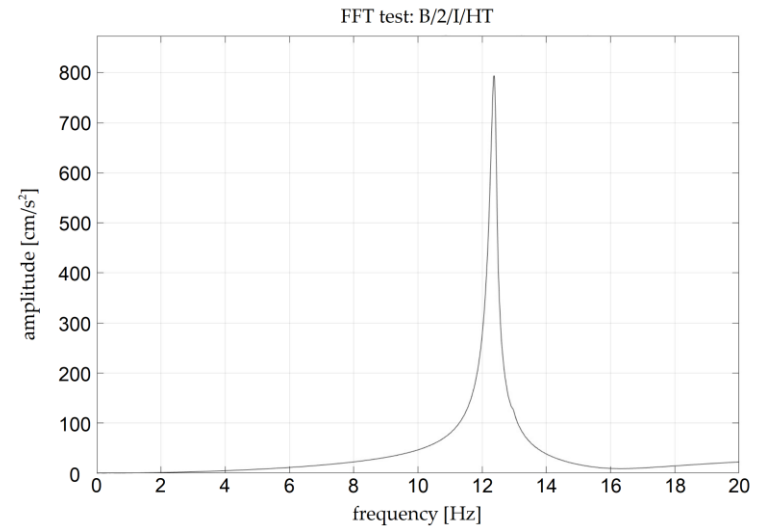
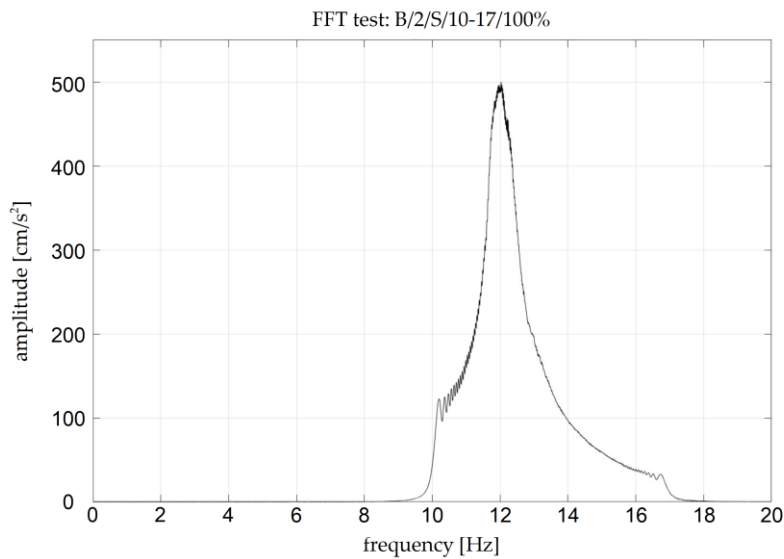


Each sweep lasted 120 seconds with frequency increasing linearly from the initial value up to terminal value.

Testing procedures

Signals recorded by accelerometers were filtered with the 7th order Butterworth low-pass filter with cutoff frequency of 30 Hz.

Resonance frequencies in both sweep and impact tests were determined as the peak values of the FFT spectrum of the accelerograms.



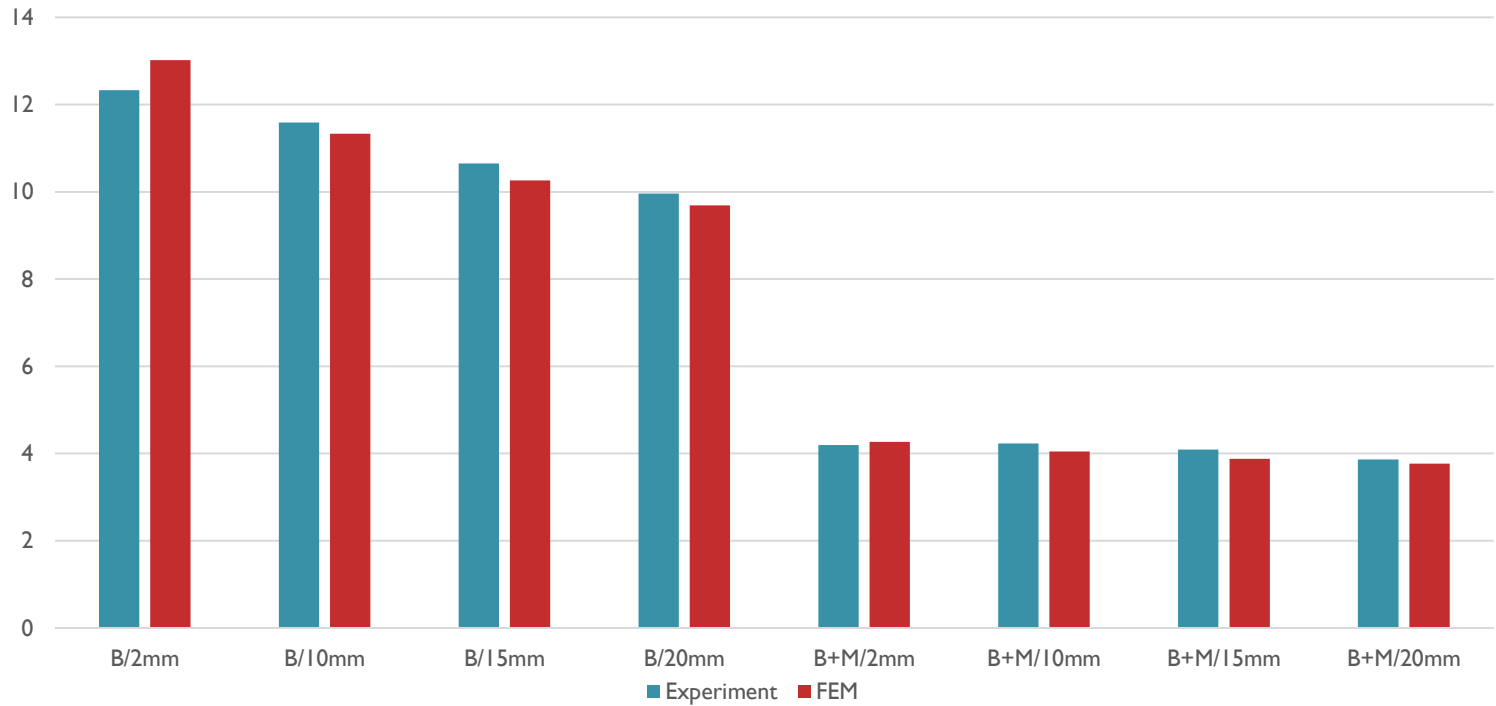
Numerical modeling



beam type	Exp.	FEA
B/2mm	12.33	13,02 (105,6%)
B/10mm	11,59	11,33 (97,8%)
B/15mm	10,65	10,26 (96,3%)
B/20mm	9,96	9,69 (97,3%)
B+M/2mm	4,19	4,27 (101,9%)
B+M/10mm	4,23	4,05 (95,7%)
B+M/15mm	4,09	3,88 (94,9%)
B+M/20mm	3,86	3,77 (97,7%)

Numerical modeling

Measured and predicted fundamental frequencies



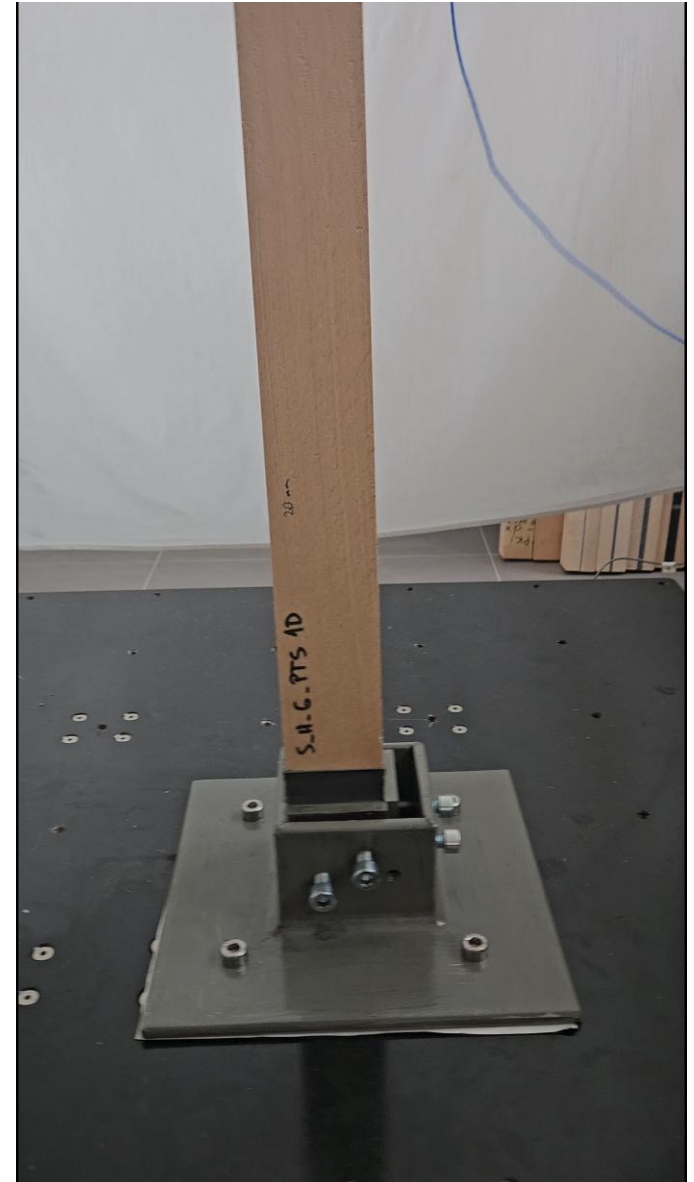
Experimental results



Experimental results



Experimental results



Experimental results



Experimental results – sweep tests

test signature	resonance frequency f [Hz]	maximal amplitude [g]	
B+M/2/S/2-6/50%	3.8415	12	B+M/2/S/2-6/50%
B+M/2/S/2-6/100%	3.5255	13	B+M/2/S/2-6/100%
B+M/2/S/2-6/150%	3.2827	16	B+M/2/S/2-6/150%
B/10/S/10-17/100%	11.3132	34	B/10/S/10-17/100%
B/10/S/10-17/150%	11.2378	45	B/10/S/10-17/150%
B/10/S/10-17/200%	10.1819	51	B/10/S/10-17/200%
B+M/10/S/2-6/50%	4.1588	12	B+M/10/S/2-6/50%
B+M/10/S/2-6/100%	4.1849	14	B+M/10/S/2-6/100%
B+M/10/S/2-6/150%	3.4433	16	B+M/10/S/2-6/150%
B/15/S/8-12/100%	10.367	53	B/15/S/8-12/100%
B/15/S/8-12/150%	10.3171	66	B/15/S/8-12/150%
B/15/S/8-12/200%	10.5321	75	B/15/S/8-12/200%
B+M/15/S/2-6/50%	4.0571	137.1375	B+M/15/S/2-6/50%
B+M/15/S/2-6/100%	3.5908	148.0918	B+M/15/S/2-6/100%
B+M/15/S/2-6/150%	3.6499	165.1687	B+M/15/S/2-6/150%
B/20/S/8-12/100%	9.6575	669.7734	B/20/S/8-12/100%
B/20/S/8-12/150%	9.5655	890.1436	B/20/S/8-12/150%
B/20/S/8-12/200%	9.6202	1032.5439	B/20/S/8-12/200%
B+M/20/S/2-6/50%	3.7112	183.1002	B+M/20/S/2-6/50%
B+M/20/S/2-6/100%	3.8283	202.531	B+M/20/S/2-6/100%
B+M/20/S/2-6/150%	3.8143	217.6114	B+M/20/S/2-6/150%

The tests are signed in the general format S/T/L/C, where:

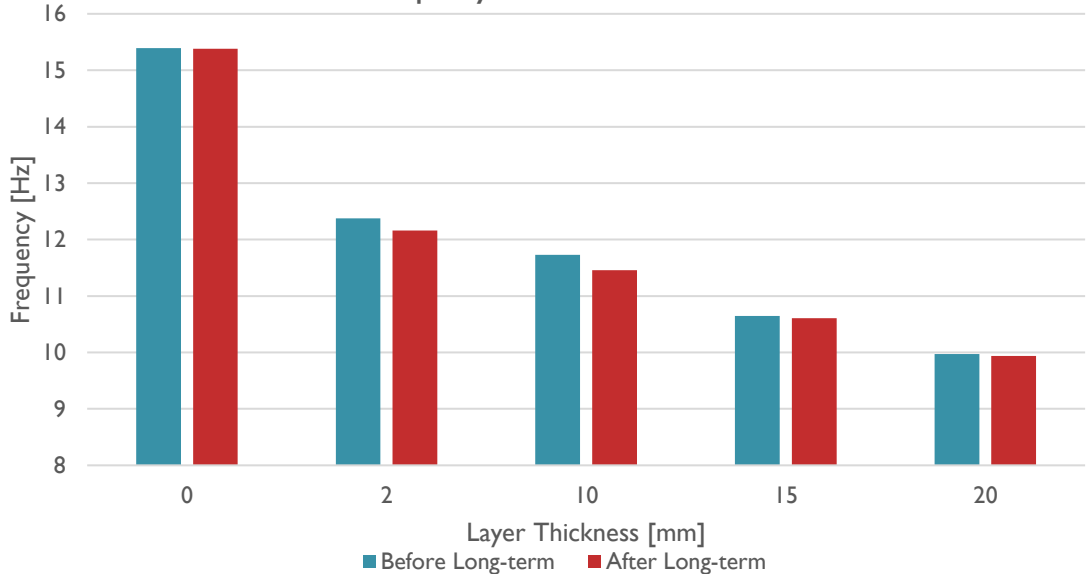
- S=B denotes a cantilever without additional mass
- S=B+M stand for beam with attached mass
- T denotes thickness of the adhesive layer in mm
- L=S indicates sweep excitation
- L=I denotes impact load
- C=HT – hitting the top of the beam
- C=HM – hitting the middle of the beam
- C=M1, C=M2 – manual deflection of the beam

Impact load tests

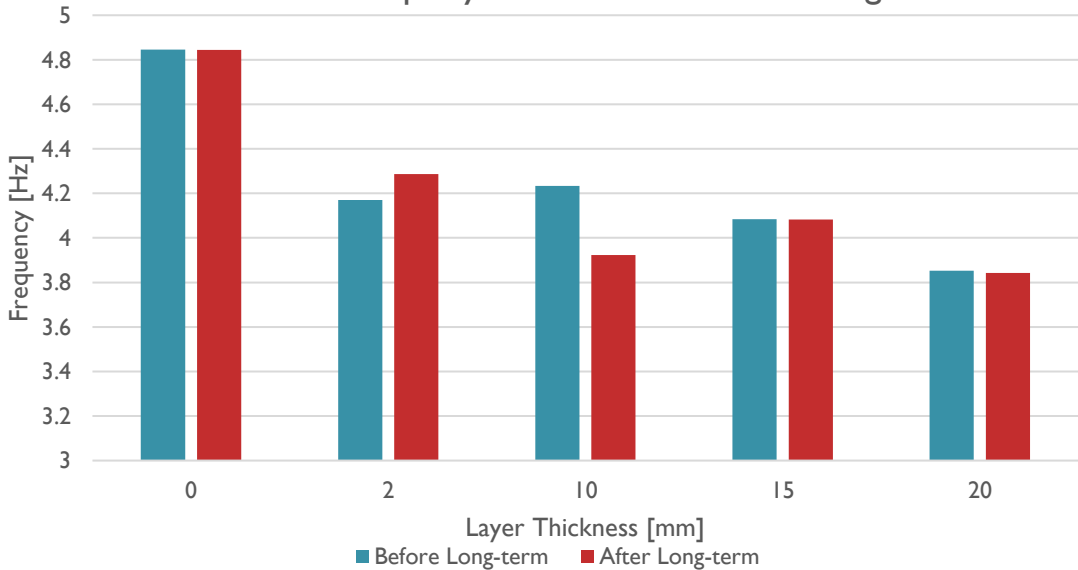
test signature	natural frequency f [Hz]	maximal amplitude a_{\max} [cm/s ²]	logarithmic decrement δ [-]	damping ratio γ [-]
B/2/I/HT	12.375	794.3143	0.0677	0.0108
B/2/I/HM	12.3671	878.3442	0.0562	0.009
B/2/I/M1	12.375	793.8866	0.0532	0.0085
B/2/I/M2	12.21	577.8685	0.0678	0.0108
B+M/2/I/HT	4.1697	105.5988	0.1168	0.0186
B+M/2/I/HM	4.1737	72.7273	0.0733	0.0117
B+M/2/I/M1	4.1583	173.6216	0.0539	0.0086
B+M/2/I/M2	4.2568	183.0667	0.0462	0.0074
B/10/I/HT	11.7321	501.2492	0.1087	0.0173
B/10/I/HM	11.7188	542.1618	0.1131	0.018
B/10/I/M1	11.4706	344.8527	0.1169	0.0186
B/10/I/M2	11.439	501.5453	0.1019	0.0162
B+M/10/I/HT	4.2339	138.3265	0.0969	0.0154
B+M/10/I/HM	4.2391	76.4188	0.4939	0.0784
B+M/10/I/M1	4.2366	164.1392	0.0538	0.0086
B+M/10/I/M2	4.2117	107.524	0.0658	0.0105
B/15/I/HT	10.6481	744.964	0.0847	0.0135
B/15/I/HM	10.6515	597.538	0.0878	0.014
B/15/I/M1	10.6452	637.2318	0.0829	0.0132
B/15/I/M2	10.6567	587.5158	0.0824	0.0131
B+M/15/I/HT	4.0843	124.1064	0.6892	0.109
B+M/15/I/HM	4.0873	92.318	0.5911	0.0937
B+M/15/I/M1	4.0829	146.2231	0.0626	0.01
B+M/15/I/M2	4.0795	158.7689	0.0639	0.0102
B/20/I/HT	9.971	697.5629	0.0742	0.0118
B/20/I/HM	9.96	818.4322	0.0773	0.0123
B/20/I/M1	9.9556	878.7887	0.0766	0.0122
B/20/I/M2	9.9438	856.5623	0.0653	0.0104
B+M/20/I/HT	3.8531	172.0414	0.7505	0.1186
B+M/20/I/HM	3.8544	87.5039	0.5866	0.093
B+M/20/I/M1	3.8527	191.3721	0.0531	0.0085
B+M/20/I/M2	3.8451	230.3046	0.0548	0.0087

Frequencies - low and high stresses

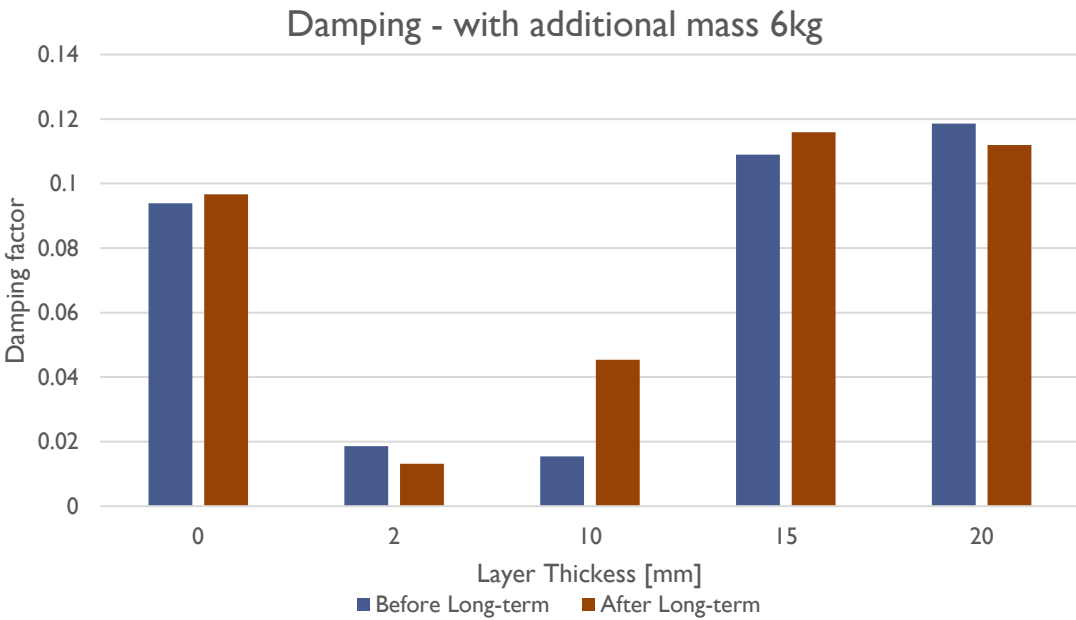
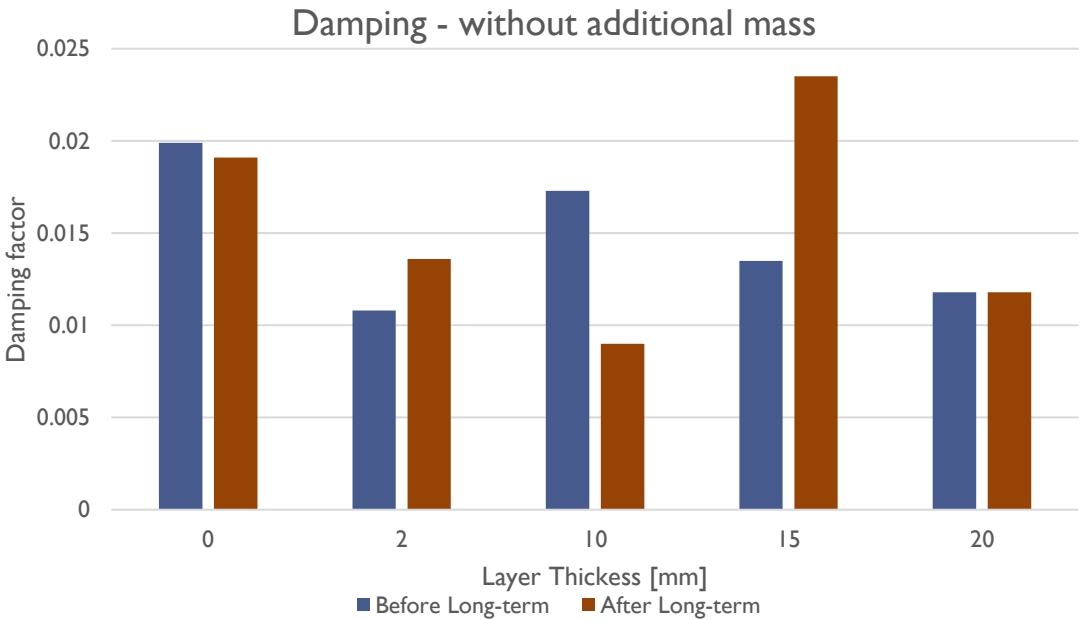
Natural frequency - without additional mass



Natural frequency - with additional mass 6kg



Damping - low and high stresses



Conclusions

Sweep tests clearly indicated that the response of the adhesively bonded beam is nonlinear – resonance frequencies were observed to drop as the amplitude of excitation increased.

There are two main reasons explaining this observation:

- the deflections of the cantilevers vibrating due to sweep loads exceeded the magnitudes commonly accepted as small deformations
- the polyurethane adhesive under consideration has also nonlinear material characteristics.

Further research will be focused on analyzing other types of flexible polyurethane adhesives, on the influence of deformation history (cyclic loads) on mechanical properties of adhesives as well as on global response of composite beams.

The problem of nonlinearity of dynamic response in case of large deformations should also be the subject of an in-depth investigation.