Research on Vibrational Performance of Timber Flooring Systems at Napier University in the UK

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SCHOOL OF ENGINEERING AND THE BUILT ENVIRONMENT

NAPIER UNIVERSITY
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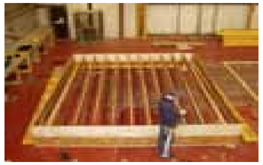
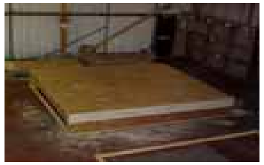
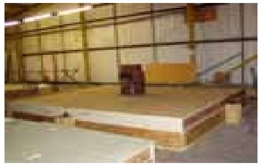
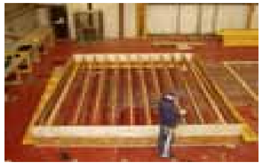
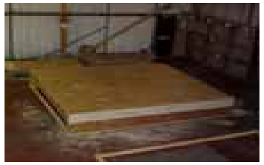
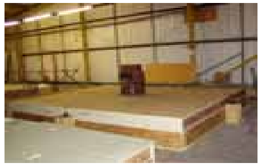




Contents of presentation

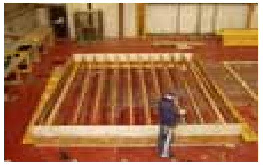
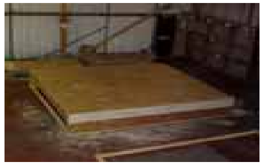
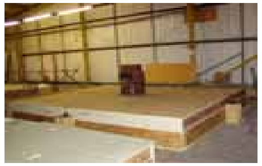
- Background and objectives of the research
- Existing problems
- Current research
- Conclusions
- Future work

Background of the project

Lightweight flooring structures easily get excited and start to vibrate:

- Occupants may get annoyed by excessive floor vibrations;
- Current design rules do not satisfactorily control floor vibrations;
- Design rules are not fully harmonised within EU.



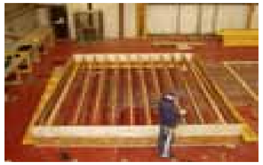
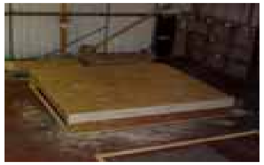
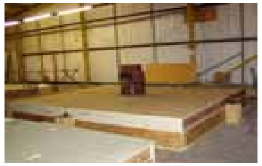
Objectives of the research work

Related to objectives of WG 1 of COST Action E55:

Analysis of the mechanisms leading to failure and **malfunctioning**

Focusing on vibrational performances of timber floor

- Determining the effect of floor configurations experimentally and theoretically using current (UK) timber floor construction styles
- Providing information for improvement of floor performance
- Developing guidelines on improving SLS timber floor design rules

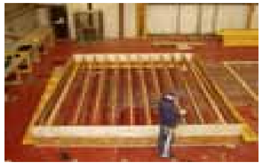
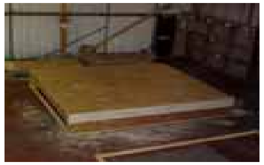
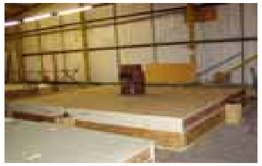





Design rules related with timber floor vibrations

Serviceability Limit States (SLS) in Eurocode 5

Requiring fundamental frequency to be > 8 Hz

- Limiting unit point load deflection
- Limiting unit impulse velocity response
  - Including a fixed damping ratio

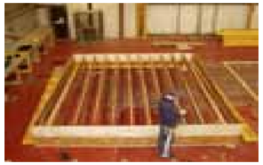
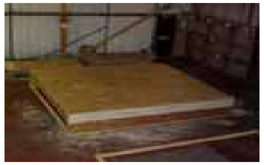
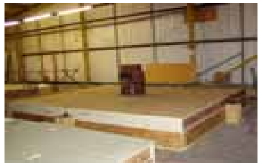





Design rules related with timber floor vibrations

Main problems

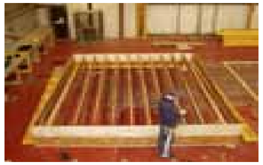
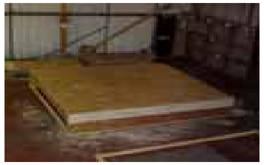
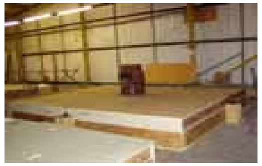
- Damping ratio
  - fixed for all timber flooring structures
    - damping characteristics vary from structure to structure and practically from mode to mode
  - recently increased by 100 % in UK NA to EC5

    => may make velocity criterion redundant in common cases
- Design rules limited to certain construction types only
- Calculation of unit impulse velocity response and limit unsure

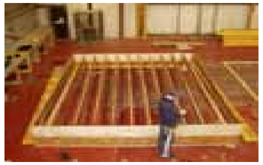
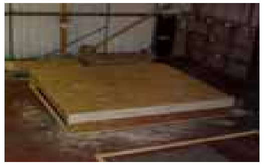
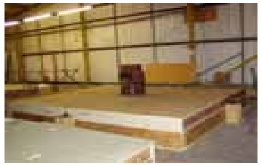





Parameters investigated for timber flooring systems

- Floor dimensions
- Floor decking materials
- Methods of fixing decking to joists
- Boundary conditions
- Dead weight
- Joist dimensions
- Joist arrangements
- Blocking

Floor construction

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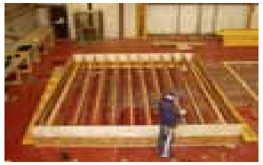
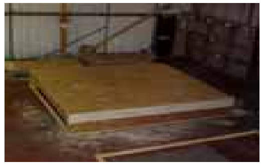
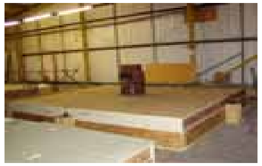

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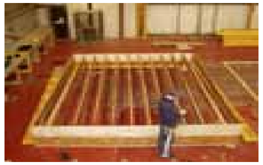
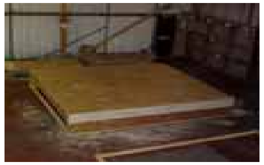
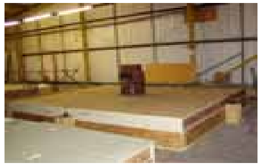

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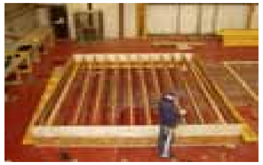
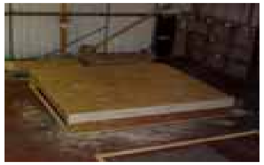
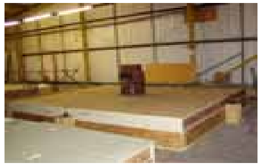
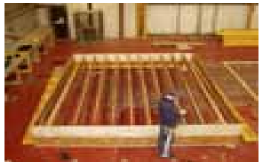
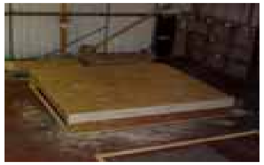
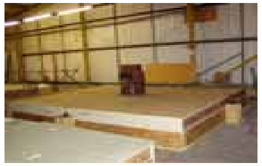
     

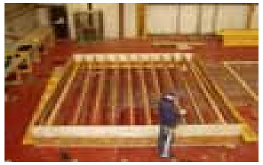
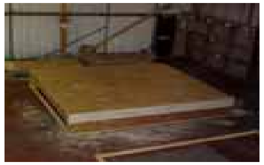
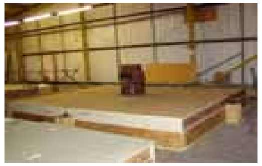
Floor construction

Experimental work

Test procedures

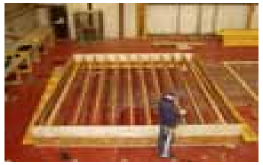
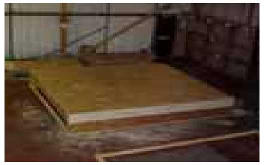
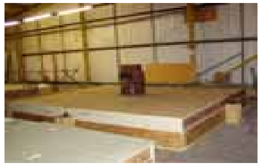
- Operational modal analysis (OMA)
  - natural frequencies and corresponding mode shapes
  - damping ratios
- Floor deflection
  - deflection under unit static point load

Experimental work

Deflection of the floor under unit point load

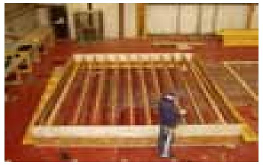
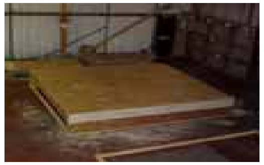
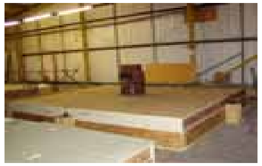
- Steel sections used for the point load
- Dial gauges used for measuring deflection

Experimental work

Main components of test equipment used for OMA

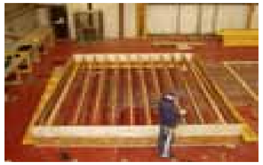
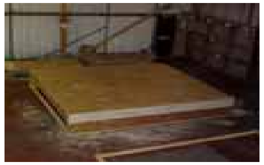
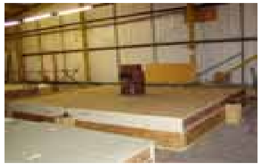
- Teac data recorder
- Pinocchio Vibraphones (transducers/sensors)
- Laptop (ARTeMIS software package)
- Brush

Experimental work

Dynamic tests

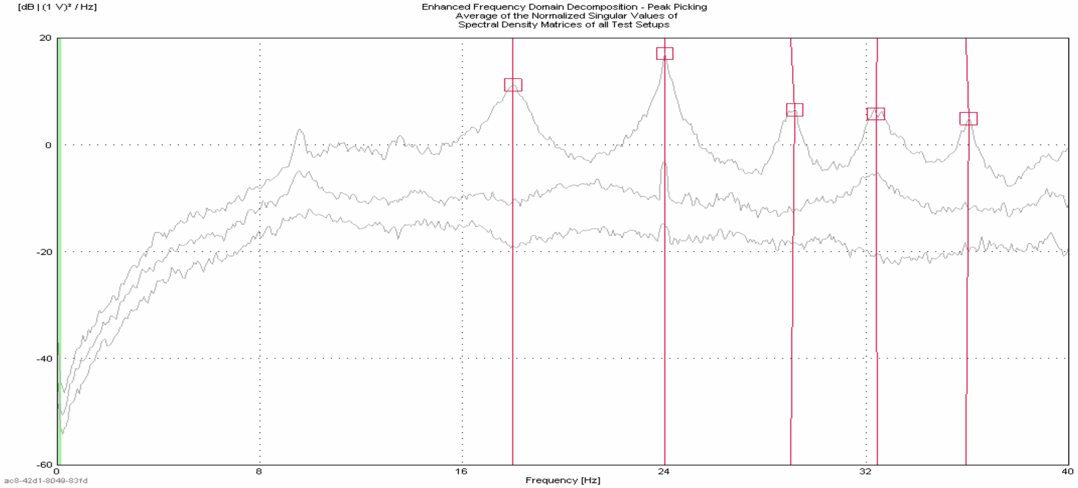
- Grid drawn on the floor surface
- Sensors attached at node points
- Brush used for exciting the floor



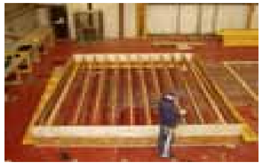
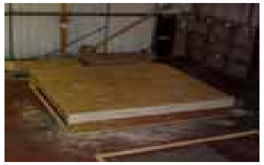
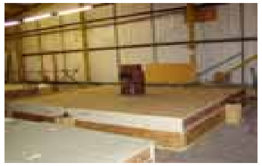
Experimental work

Signal processing and analysis

Dynamic responses of the structure displayed as spectral densities in the frequency domain



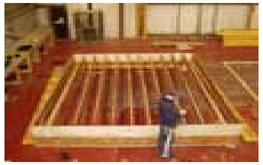
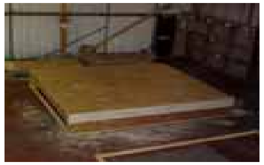
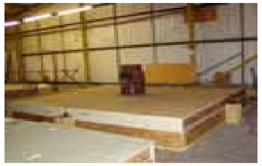
The response of floor FT-1B-Pb in the frequency domain with the first five natural frequencies selected

Results of testing programme 1 (preliminary)

Testing programme 1

Floor	Size [m]	Configurations
FT-1A-Pa	3.7×4.4	simply supported along two edges, P5 screwed to joists
FT-1A-Pb	3.7×4.4	simply supported along two edges, P5 glued + screwed to joists
FT-1A-O	3.7×4.4	simply supported along two edges, OSB screwed to joists
FT-1B-Pa	3.7×4.4	semi-rigidly supported along two edges, P5 screwed to joists
FT-1B-Pb	3.7×4.4	semi-rigidly supported along two edges, P5 glued + screwed to joists
FT-1B-O	3.7×4.4	semi-rigidly supported along two edges, OSB screwed to joists
FT-2A-Pa	5.0×4.4	simply supported along two edges, P5 screwed to joists
FT-2A-Pb	5.0×4.4	simply supported along two edges, P5 glued + screwed to joists
FT-2A-O	5.0×4.4	simply supported along two edges, OSB screwed to joists
FT-2B-Pa	5.0×4.4	semi-rigidly supported along two edges, P5 screwed to joists
FT-2B-Pb	5.0×4.4	semi-rigidly supported along two edges, P5 glued + screwed to joists
FT-2B-O	5.0×4.4	semi-rigidly supported along two edges, OSB screwed to joists

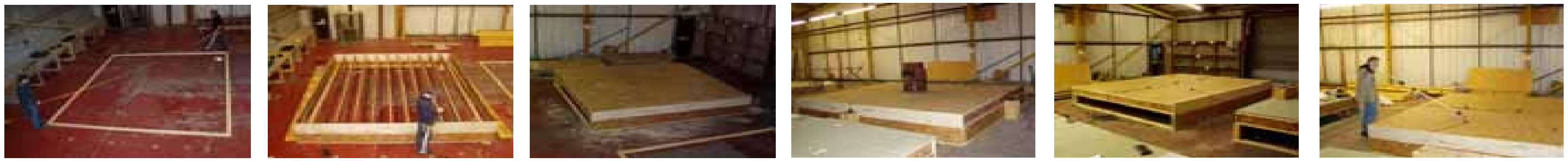
Results of testing programme 1 (preliminary)

Testing programme 1

- Unit point load deflection
- Natural frequencies
- Mode shapes
- Damping ratios

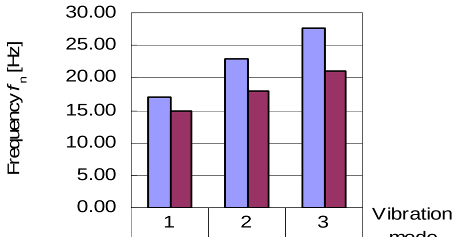
Results detailed in:

Weckendorf, J., Zhang, B., Kermani, A. and Reid, D. (2007), *Vibrational behaviour of timber floors – experimental investigations,* The 3rd PRoBE Conference, Glasgow Caledonian University, Glasgow, UK.

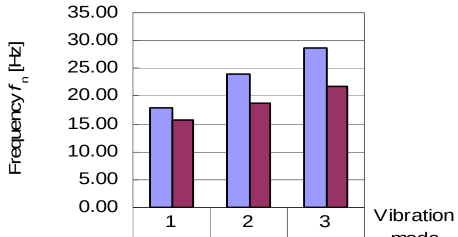


Results of testing programme 1 (preliminary)

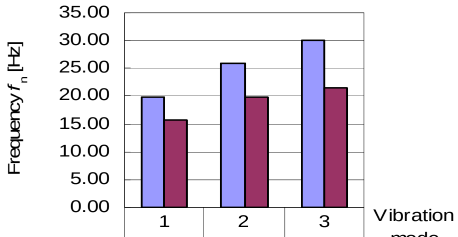
Effects of increased floor length*: Reducing frequencies



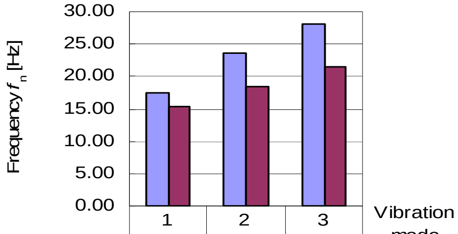
	1	2	3
FT-1A-Pa	17.00	22.99	27.70
FT-2A-Pa	14.97	17.85	20.92



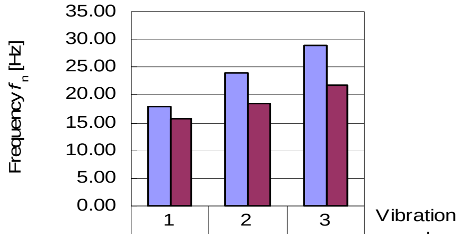
	1	2	3
FT-1A-Pb	17.96	24.00	28.63
FT-2A-Pb	15.63	18.64	21.68



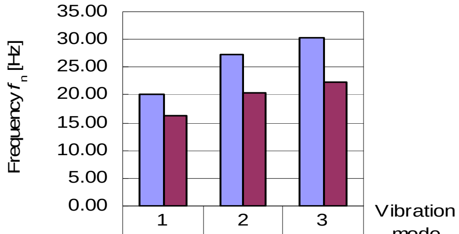
	1	2	3
FT-1A-O	19.71	25.87	29.98
FT-2A-O	15.80	19.76	21.63



	1	2	3
FT-1B-Pa	17.53	23.58	28.06
FT-2B-Pa	15.24	18.51	21.48

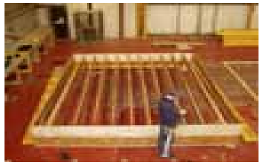
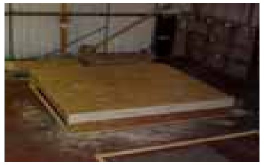
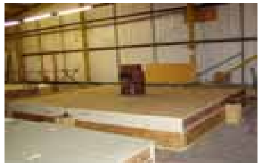


	1	2	3
FT-1B-Pb	18.01	24.04	29.00
FT-2B-Pb	15.63	18.53	21.66



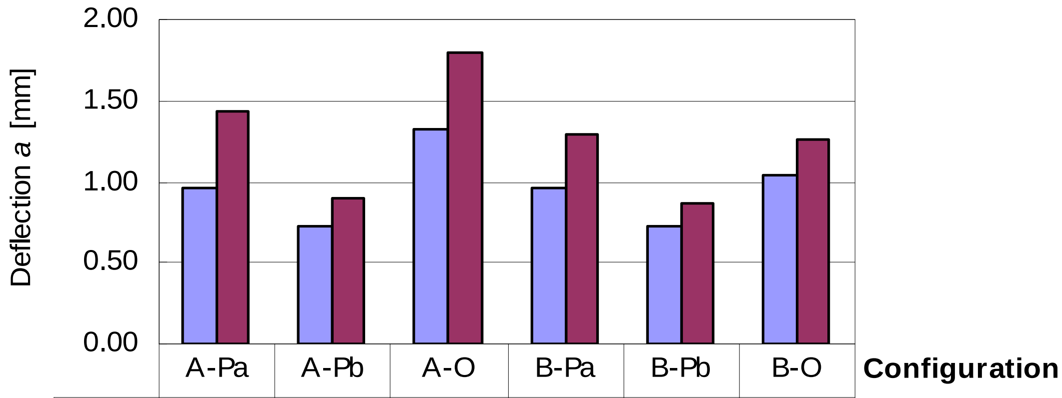
	1	2	3
FT-1B-O	20.12	27.17	30.39
FT-2B-O	16.21	20.53	22.29

* Flexural rigidity of the joists has been increased for long-span floor.

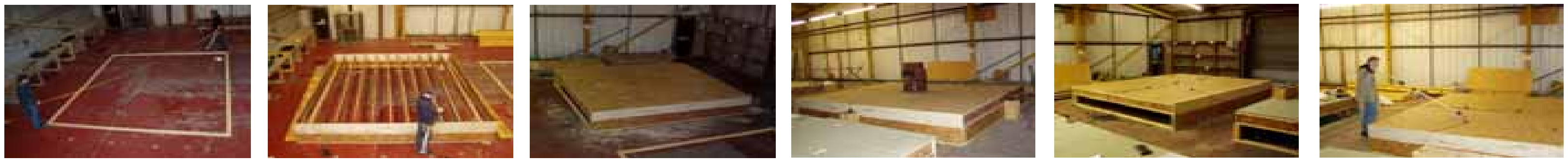
Results of testing programme 1 (preliminary)

Effects of increased floor length*: Increasing deflections



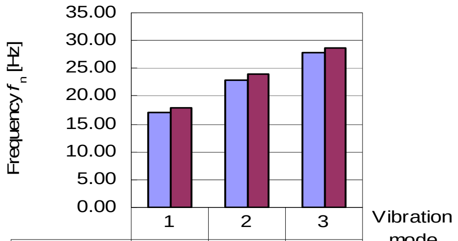
	A-Pa	A-Pb	A-O	B-Pa	B-Pb	B-O
FT-1	0.97	0.72	1.32	0.96	0.72	1.04
FT-2	1.44	0.90	1.79	1.29	0.87	1.26

* Flexural rigidity of the joists has been increased for long-span floor.

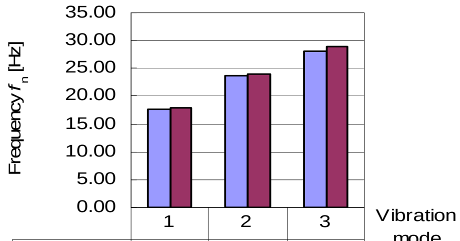


Results of testing programme 1 (preliminary)

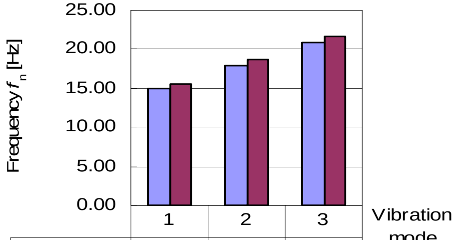
Effects of using glue in addition to screws: Increasing frequencies



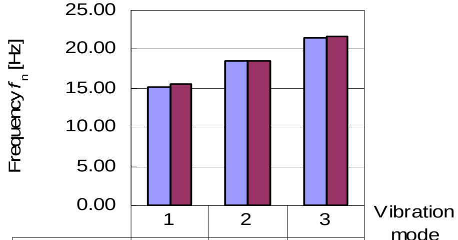
Vibration mode	1	2	3
FT-1A-Pa	17.00	22.99	27.70
FT-1A-Pb	17.96	24.00	28.63



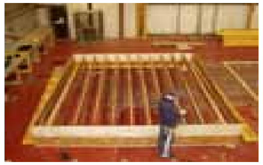
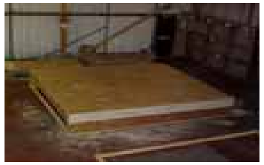
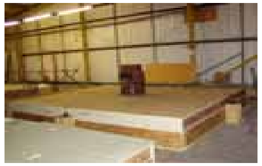
Vibration mode	1	2	3
FT-1B-Pa	17.53	23.58	28.06
FT-1B-Pb	18.01	24.04	29.00



Vibration mode	1	2	3
FT-2A-Pa	14.97	17.85	20.92
FT-2A-Pb	15.63	18.64	21.68

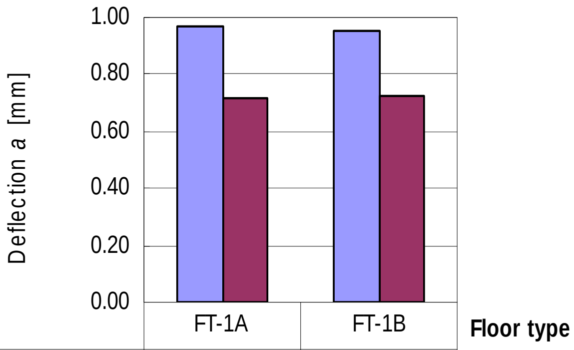


Vibration mode	1	2	3
FT-2B-Pa	15.24	18.51	21.48
FT-2B-Pb	15.63	18.53	21.66

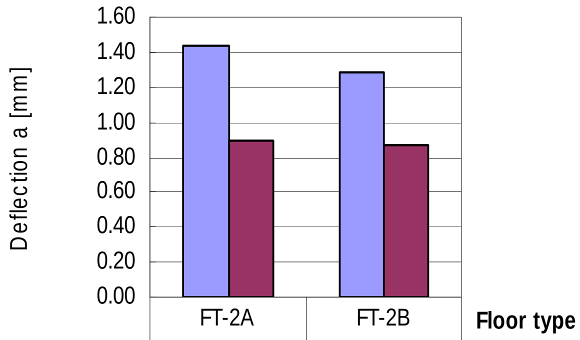





Results of testing programme 1 (preliminary)

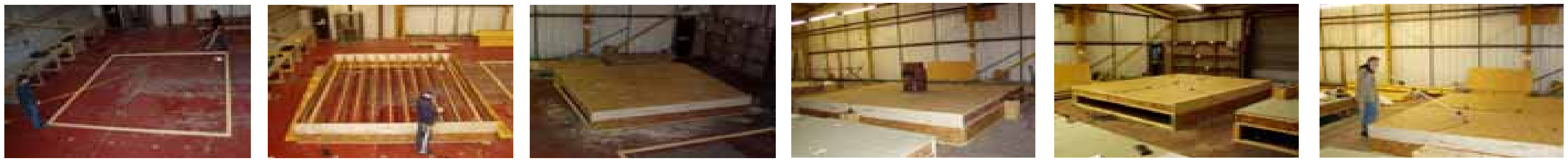
Effects of using glue in addition to screws: Decreasing deflection



	FT-1A	FT-1B
Screws only	0.97	0.96
Glue + Screws	0.72	0.72

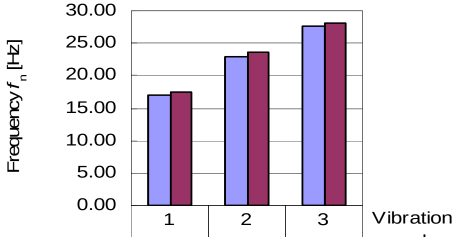


	FT-2A	FT-2B
Screws only	1.44	1.29
Glue + Screws	0.90	0.87

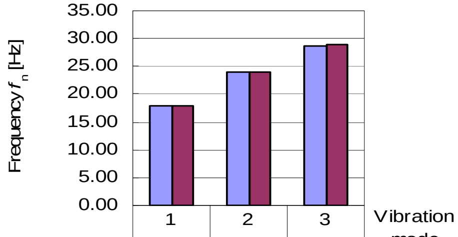


Results of testing programme 1 (preliminary)

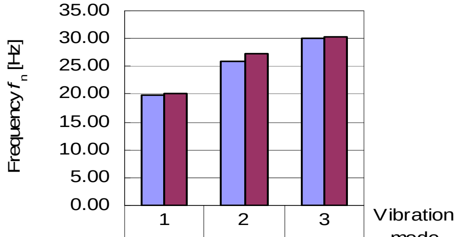
Effects of providing end fixity: Increasing frequencies



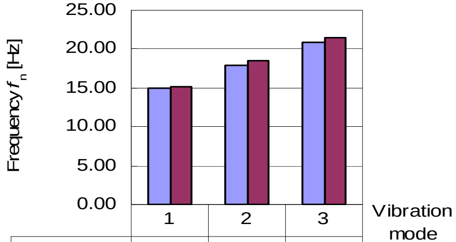
Vibration mode	1	2	3
FT-1A-Pa	17.00	22.99	27.70
FT-1B-Pa	17.53	23.58	28.06



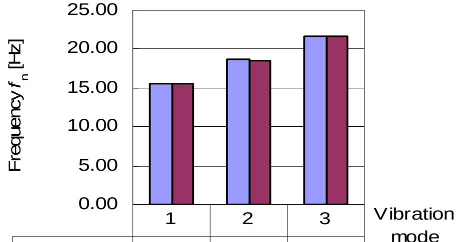
Vibration mode	1	2	3
FT-1A-Pb	17.96	24.00	28.63
FT-1B-Pb	18.01	24.04	29.00



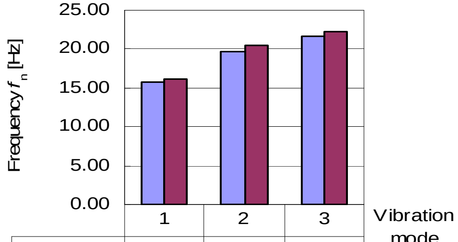
Vibration mode	1	2	3
FT-1A-O	19.71	25.87	29.98
FT-1B-O	20.12	27.17	30.39



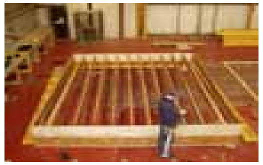
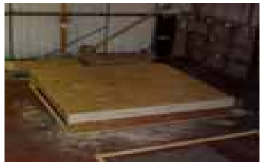
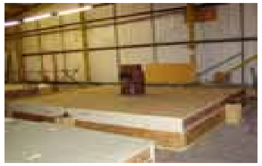
Vibration mode	1	2	3
FT-2A-Pa	14.97	17.85	20.92
FT-2B-Pa	15.24	18.51	21.48



Vibration mode	1	2	3
FT-2A-Pb	15.63	18.64	21.68
FT-2B-Pb	15.63	18.53	21.66

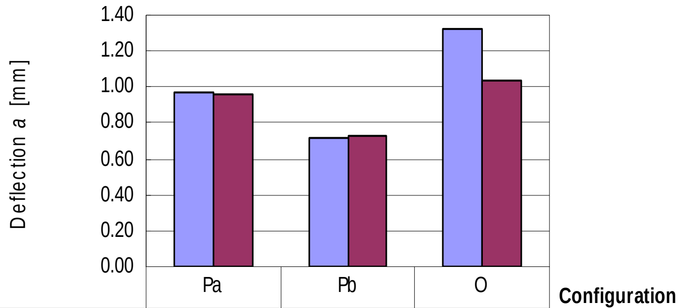


Vibration mode	1	2	3
FT-2A-O	15.80	19.76	21.63
FT-2B-O	16.21	20.53	22.29

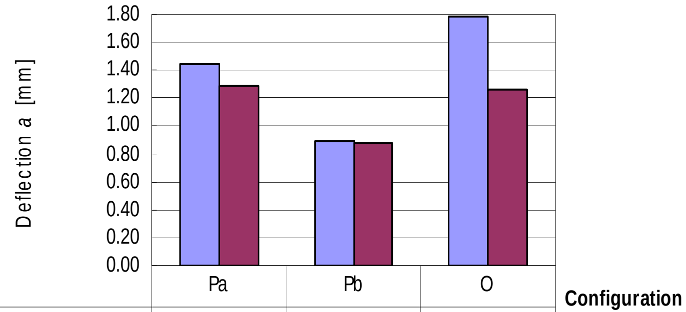
Results of testing programme 1 (preliminary)

Effects of providing end fixity : Decreasing deflections



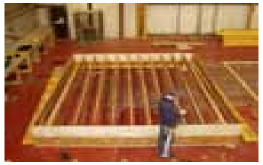
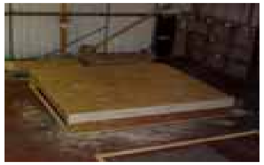
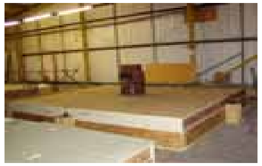
	Pa	Pb	O
FT simply supported	0.97	0.72	1.32
FT screwed to supports	0.96	0.72	1.04

L = 3.7 m



	Pa	Pb	O
FT simply supported	1.44	0.90	1.79
FT screwed to supports	1.29	0.87	1.26

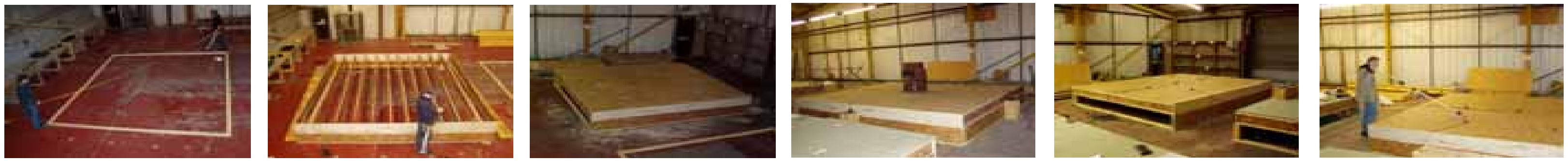
L = 5.0 m

Results of testing programme 2 (preliminary)

Testing programme 2 (Part 1 - Variation in self weight)

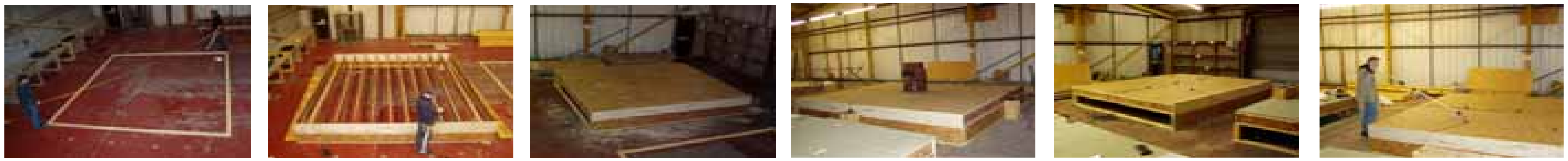
Floor	Size [m]	Configurations
FJ-2B-20	3.5×2.4	semi-rigid supported along two edges, P5 screwed to joists, 19,90 kg/m^2
FJ-2B-50	3.5×2.4	semi-rigid supported along two edges, P5 screwed to joists, 50,00 kg/m^2
FJ-2B-75	3.5×2.4	semi-rigid supported along two edges, P5 screwed to joists, 75,00 kg/m^2



Results of testing programme 2 (preliminary)

Testing programme 2 (Part 1 - Variation in self weight)

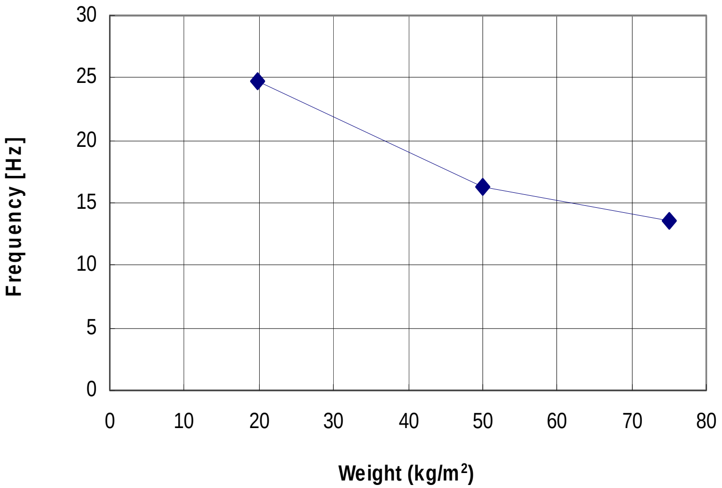
- Unit point load deflection
- Natural frequencies
- Mode shapes
- Damping ratios

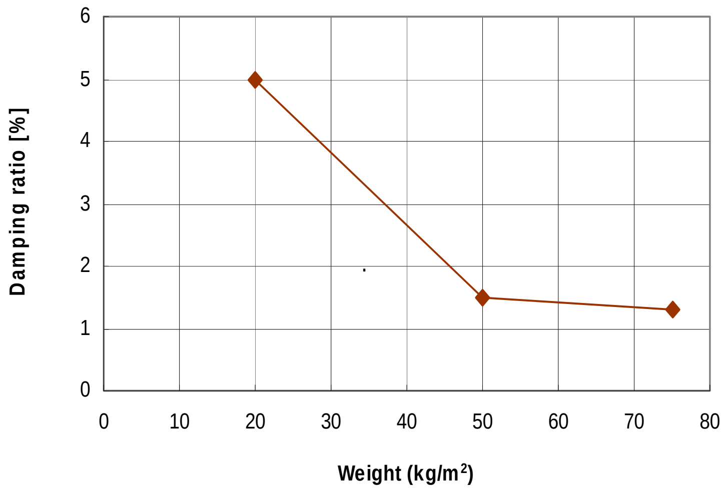


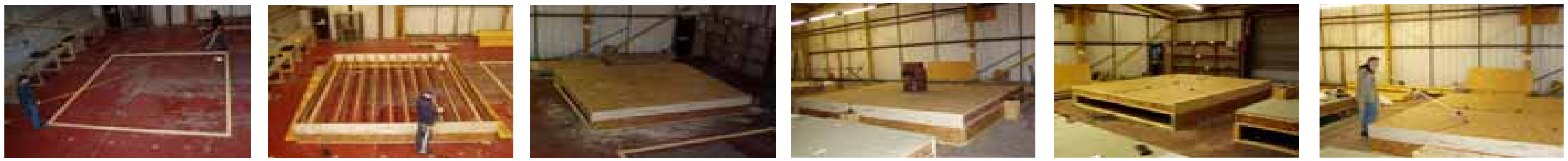
Results of testing programme 2 (preliminary)

Increasing dead weight:

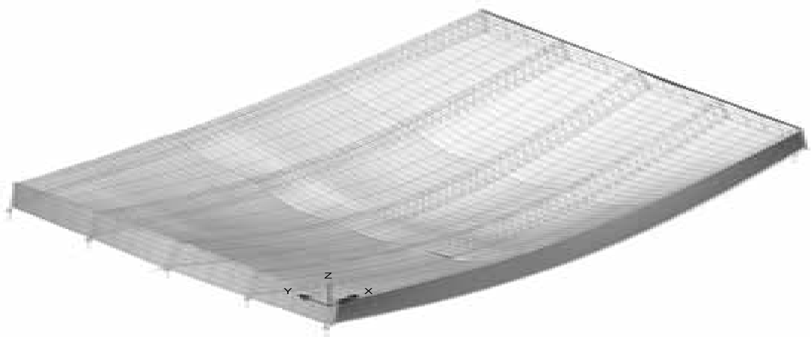
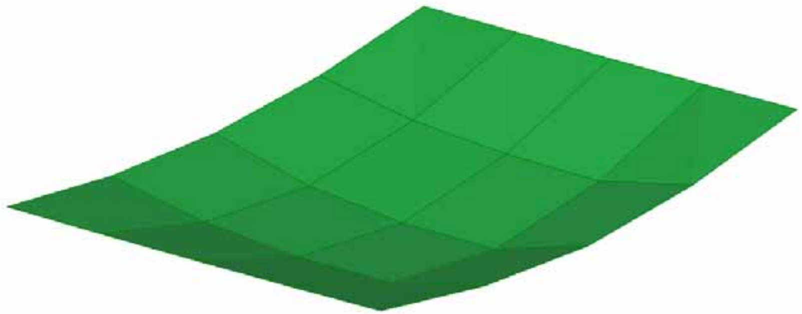
- Reducing frequencies
- Reducing damping ratios

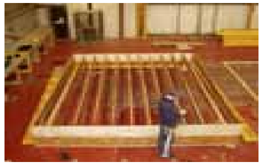
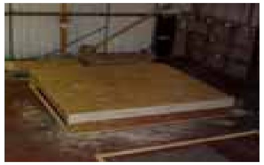
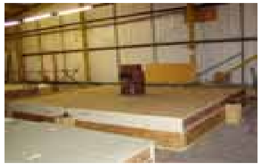




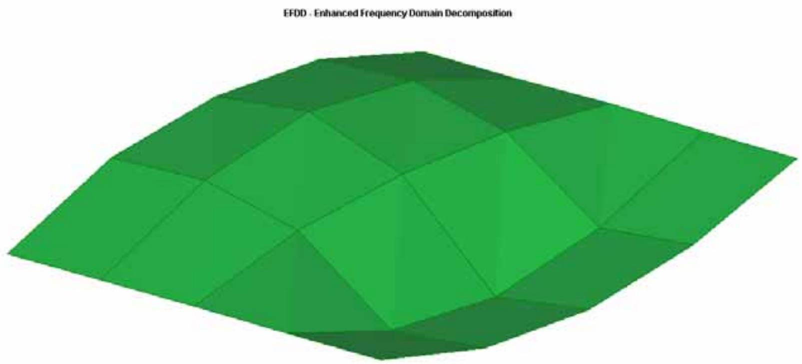


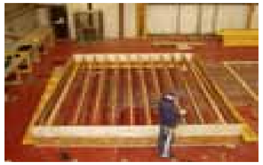
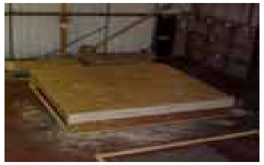
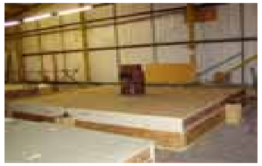
Results of testing programme 2 (preliminary)

FEM Prediction	Measured Result
Mode 1	
	
$f_{1,\ \mathrm{FEM}} = 28.2$ Hz	$f_{1,\ \mathrm{EXP}} = 24.8$ Hz

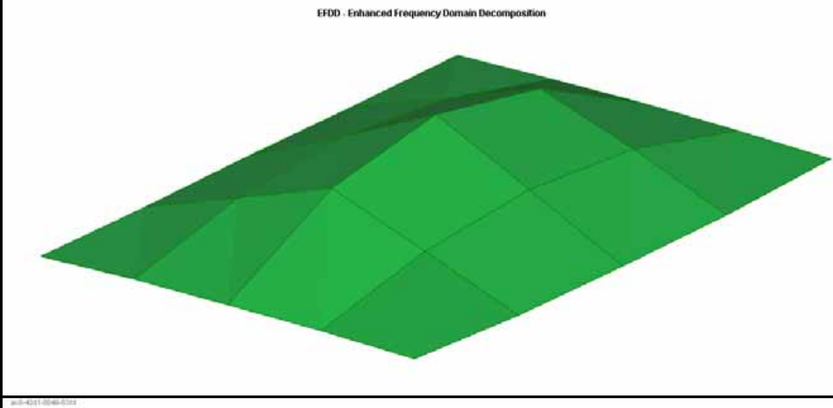
     

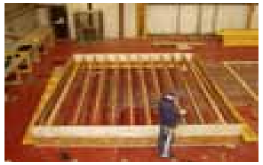
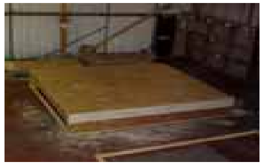
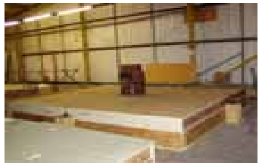
Results of testing programme 2 (preliminary)

FEM Prediction	Measured Result
Mode 2	
	
$f_{2,\ FEM} = 31.9$ Hz	$f_{2,\ EXP} = 30.7$ Hz

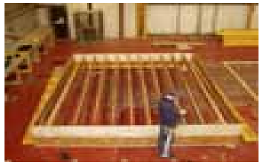
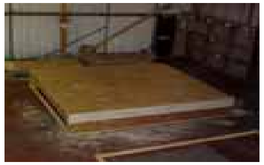
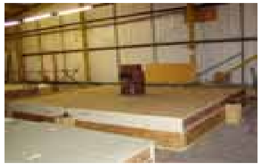
Results of testing programme 2 (preliminary)

FEM Prediction	Measured Result
Mode 3	
	
$f_{3,\ FEM}$ = 37.2 Hz	$f_{3,\ EXP}$ = 36.2 Hz

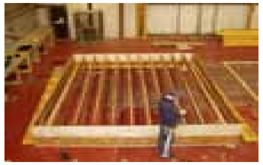
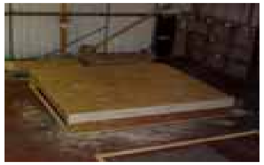
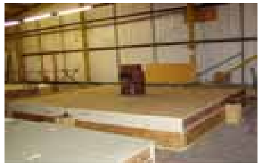
Conclusions

- Current design rules are not always satisfactory.
- Extensive experimental work has been carried out
  - to get a better understanding of the problem
  - to assess the effects of varied parameters to dynamic response
    - mass and span highly influence the vibrational performance
  - to gain further information for enhancing design criteria.
- The undertaken FEM simulation provides promising results.
- Enhanced formulations are needed.

Future work

- Comparing measured and calculated results
- Establishing relationships of floor set-ups with respect to
  - natural frequencies and mode shapes
  - damping ratios
- Updating the FE-model
- Undertaking Short Term Scientific Mission of COST E55 in cooperation with VTT Technical Research Centre of Finland
- Producing enhanced guidelines for design

Acknowledgements

Oregon Timber Frame Ltd. provided facilities and the materials including TJI-joists for testing programme one.

James Jones & Sons Ltd. provided materials for testing programme two.

Their support is gratefully acknowledged.

Thank you !