ACOUSTIC TESTING OF A *PINUS RADIATA* POLE JOIST FLOOR SYSTEM

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ABSTRACT

The overall aim of the research is to eventually develop a viable system, using *Pinus radiata*, for multi-storey timber buildings up to six storeys. One of the main issues is achieving sound resistant timber floors that are economically viable. This paper reports on the acoustic testing of a prototype floor built with Radiata pole joists. Measurements were made of the objective performance. The results indicate that the floor meets code requirements – even when it has a hard surface.

1. INTRODUCTION

A worldwide interest in multi-storey timber buildings is expected due to the environmental advantages of timber construction when compared to concrete and steel.

This paper reports on the acoustic behaviour of a prototype floor incorporating Radiata pole joists placed at 600 mm centres. Poles have been used for the joists in an attempt to reduce costs and make it more competitive with typical pre-stressed floor systems. The prototype floor in the tests incorporates findings from recent research undertaken at the Acoustics Research Centre of the University of Auckland. This initial research, which was sponsored by the Forest and Wood Products Research and Development Corporation of Australia, aimed to investigate and extend our understanding of how timber floors can be designed to provide sound insulation - both for airborne and impact sound - comparable with that achievable with typical concrete floor constructions which meet the Australian and NZ building code requirements. Of particular concern was the low frequency range currently not included in formal performance measures used in our building codes - i.e. frequencies below 100 Hz.

From a wide ranging parametric study together with objective testing and subjective assessment of the insulation provided by a wide range of purpose-built test floors (incorporating variations in component properties and design which are buildable using existing construction skills), a generic solution floor has been proposed [1] which has guided the design of the floor described here. Subjective assessments of the generic solution floor which used a range of impact sources (i.e. lightweight and heavy standard impact sources, walking, running and cutlery drops) demonstrated that the floor performed equal to or better than the reference concrete floor used for comparison, depending on the impact source [2] [3].

The floor described in this paper is a specific realisation of the generic floor but using Radiata poles for the joists in place of engineered '**I**' joists. Replacing the 'I' joists with timber poles reduces the timber floor costs by $20/m^2 [4]. However, it is still more expensive than an equivalent reinforced concrete floor. A disadvantage of the pole joists, when compared to the engineered 'I' joists, is that they are considerably heavier, and will need cranage and require marginally larger floor beams and columns, etc. However, an acoustical advantage may result from the fact that the poles have greater stiffness laterally and their cross-sections have more individual variation. Consequently the floor's overall response to sound and peaks in its frequency response will be reduced.

2. PROTOTYPE FLOOR WITH POLE JOISTS FOR ACOUSTIC TESTING

A test floor of approximately 50 sq.m. was constructed with 200 mm dia. Radiata pole joists @ 600 mm centres as per Figures 1 & 2. The strength and deflection criteria for the floor were checked according to the appropriate building code [8]. Timber floors previously developed by a team that included the Acoustic Research Centre guided the design of the flooring and ceiling components. The main difference is that this test floor

Figure 1. Floor test rig, 200 small

Figure 2. FloorTest Rig, End dia. pole @ 600mm centres. Measuring the sound field .

used timber pole joists, and the previous floors used engineered 'I' joists.

The tapered poles have two opposite faces cut at 205 mm apart to provide consistent depth and flat surfaces for connecting flooring and ceiling elements. The advantages of the pole joists, when they are compared to engineered 'I' joists, are that they are cheaper to buy, require less heat to manufacture, and involve less discharge of CO^2 into the atmosphere. Also, an acoustic advantage may be that because all pole cross-sections vary, the joists are less likely to resonate in unison. A disadvantage of the pole joists, when compared to the engineered 'I' joists, is that they are considerably heavier, and will need cranage and require marginally larger beams and columns etc.

2.1 FLOOR COSTING

One of the main issues for timber floors is that they are more expensive than equivalent pre-stressed concrete floor systems. Pole joists help to reduce floor costs, because the cost of 200SED joists, with two cut parallel faces, is $11.00/m and the equivalent engineered 'I' joist has a price of $22.00/m. This translates to a significant saving of $18.00 per sq.m. of floor area. The pole floor has been costed and compared to the equivalent prestressed concrete floor. The costings are derived from 'The New Zealand Building Economist', November 2009 edition. Without carpet, the timber floor complies for both impact and airbourne sound insulation as required by the relevant NZ codes. Thus, the pole floor costing includes the ply flooring being sanded and with three coats of polyurethane. However, the reinforced concrete floor, which being suitable for airbourne sound transmission, requires a reasonable quality carpet with underlay for impact sound resistance.

The costs of the pole and concrete floors are very similar, which is important for acceptance of timber floors for commercial buildings. The pole floor costing indicates that the ply is an expensive item. If the lower ply sheet is replaced by particle board, the pole floor cost reduces by $13/sq.m.

Table 1. Pole floor costing.

POLE FLOOR – CONSTRUCTED COST per SQ.M				
Item	**Unit**	**Rate**	**Quantity**	**Cost**
Plywood	m^2	51.42	2.00	102.84
Battens, 75*50	m	10.22	2.50	25.55
Sand/Sawdust	m^2	15.00	1.00	15.00
Pole Joists, untreated	m	11.00	1.67	18.33
Fiberglass Batts	m^2	23.10	1.00	23.10
Ceiling Battens	m	9.79	1.67	16.32
Gib+ Stopping	m^2	54.19	1.00	54.19
Floor Sand	m^2	6.00	1.00	6.00
Polyurethane, 3 coats	m^2	15.50	1.00	15.50
TOTAL COST				**$276.83**

Table 2. Equivalent prestressed concrete floor costing.

PRESTRESSED CONCRETE FLOOR – CONSTRUCTED COST per SQ.M				
Item	**Unit**	**Rate**	**Quantity**	**Cost**
Prestressed Floor	$\mathbf{m^2}$	169.00	1.00	169.00
Ceiling Tiles	$\mathbf{m^2}$	52.80	1.00	52.80
Carpet with Underlay	$\mathbf{m^2}$	60.00	1.00	60.00
TOTAL COST				**$281.80**

2.2 RESEARCH INTO THE INSULATION AGAINST SOUND OF THE PROTOTYPE FLOOR SYSTEM.

2.2.1 Construction and Testing

A dedicated floor-test rig for impact insulation that was built near the University's Tamaki campus for a previous research project was the test bed for the prototype floor. A building contractor was hired to build the floor (OSH regulations ruled out the building by University personnel) and the floor was completed in a timely and trouble-free manner.

The test facility – whilst not part of the Acoustic Research Centre's suite of ISO reverberation chambers with suppressed flanking transmission – meets the ISO 140 requirements for laboratory testing the impact insulation of floors. Figures 1 & 2 show the floor-test facility with the prototype floor in place; Figure 2, also, shows the set-up for measuring the IIC and Ln,w ratings. It provides for constructions to remain in place for extended periods for detailed study and experiment. This was not possible in the ARC's main chambers because of commercial use.

Normalized Impact sound pressure levels according to ISO 140-6

Date of test: 8-Dec-06

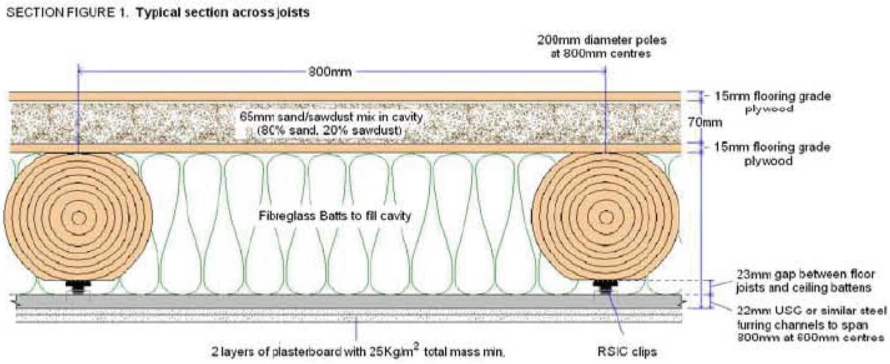
Description and identification of the test specimen and test arrangement: Client: University of Auckland

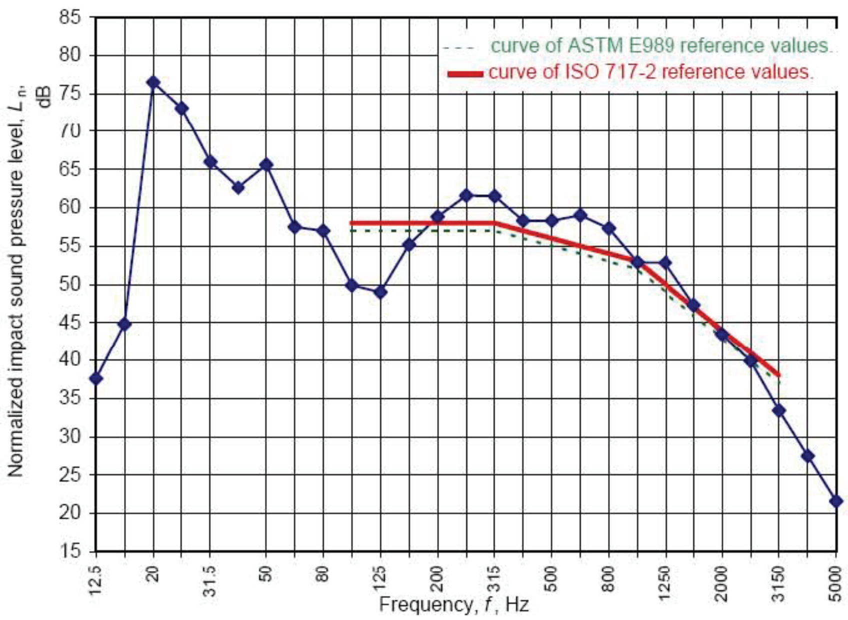
A light weight timber floor/ceiling system comprising: 15mm butt jointed plywood sheets 2700mm x 1200mm fixed with 40mm square head screws at 150mm centres onto 70mm x 45mm battens 45mm side down at 450mm centres angle screwed to 15mm but jointed plywood sheets 2700mm x 1200mm fixed with 50mm square head screws at 150mm centres to 200mm diameter pole joists at 800mm centres, the cavity between the 2 layers of Plywood is filled to 65mm deep with a mixture of 80% paving sand and 20% sawdust. The 3.2m long pole joists are "simply supported" at the ends with timber blocking between them, the pole joists are seated on 100mm x 50mm timber plates bolted at 1m centres to the concrete blockwork at either end. The floor cavity between the pole joists is lined with 2 layers of 150mm thick *Pink Batts Silencer Mid Floor* bulk fibreglass insulation. The ceiling comprises: 2 layers of 13mm *GIB Noiseline®* plasterboard fixed with 41mm screws at 300mm centres to 35mm *GIB® Rondo® furring channels* at 600mm centres and the steel perimeter J channel fixed to the timber plates, the *furring channels* are fixed to the pole joists with RSIC** clips at 800mm centres. The perimeter of the *GIB Noiseline®* plasterboard is sealed with *GIB Soundseal®* and the joints are paper taped and stopped with *GIB TradeSet® 90* stopping compound.

Area S of specimen floor: 17.60 m^2
Air temp in the test rooms: 20 °C
Air humidity in test rooms: 55 %
Receiving room volume: 52 m^3

Frequency f Hz	L_n 1/3 Octave dB
12.5	37.6
16	44.8
20	76.5
25	73.1
31.5	66.0
40	62.6
50	65.6
63	57.5
80	57.0
100	**49.9**
125	**49.0**
160	**55.2**
200	**58.8**
250	**61.6**
315	**61.5**
400	**58.3**
500	**58.3**
630	**59.0**
800	**57.3**
1000	**52.9**
1250	**52.8**
1600	**47.3**
2000	**43.5**
2500	**39.9**
3150	**33.4**
4000	27.5
5000	21.6

Notes:1.#N/A = Value not available.
2. **Bold** values are used to calculate IIC and Ln,w.
3.< indicates that the true value is lower





Rating according to ISO 717-2: $L_{n,w}$ (C_I) = 56 (-2) dB $C_{I,50\text{-}2500}$ = 0 dB

Rating according to ASTM E989: **Impact Insulation Class = 55 dB**

No. of test report: **POLEFLOOR** Name of test institute: University of Auckland Acoustics Testing Service.

Date: Signature: **Preliminary Results Only**

Figure 3. The 1/3rd octave band normalised impact sound levels measured from the prototype pole-floor, and the single-figure ratings of impact sound insulation (IIC and Ln,w) derived from them.

Airborne sound reduction indices according to ISO 140-3
Laboratory measurements of airborne sound insulation of building elements

Description and identification of the test specimen and test arrangement: Date of test:
Airborne sound insulation of a Double leaf single frame wall Client:

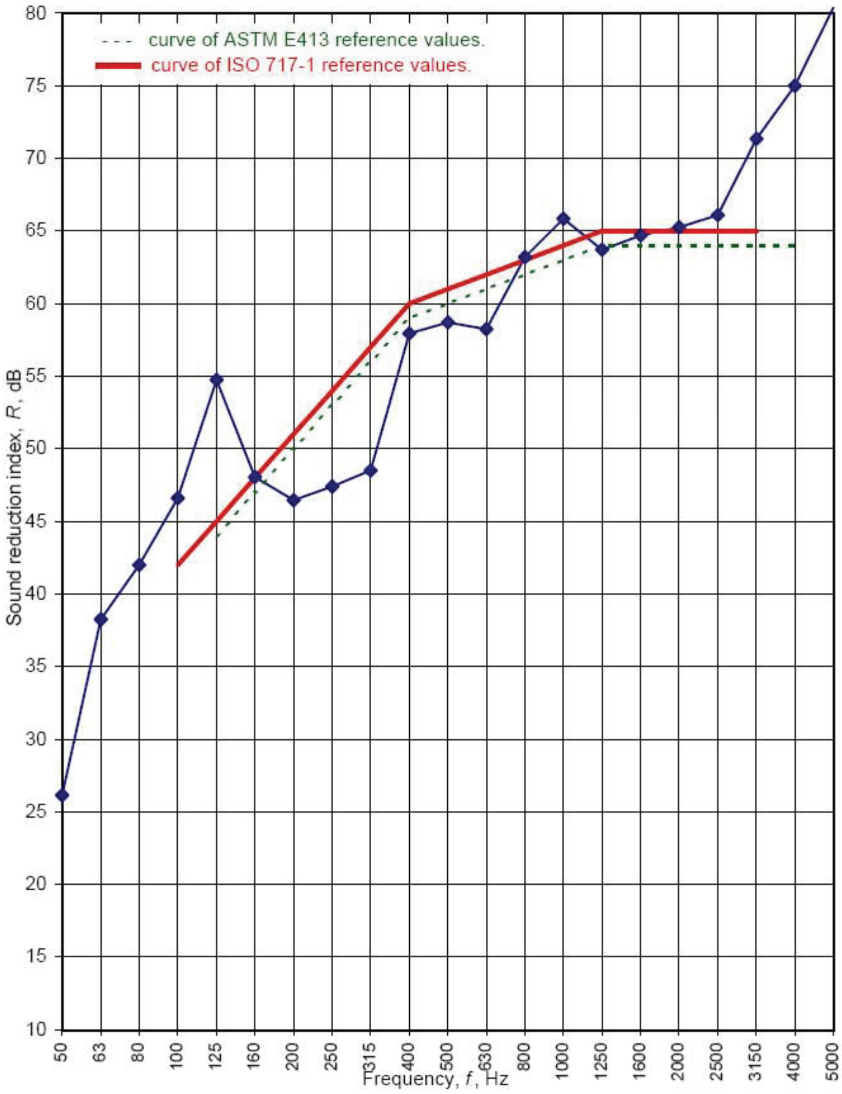
Test Wall Frame:
Test Wall Linings: Source chamber side:
Receiving chamber side:
Cavity Absorption:
Test Wall Lining Joint Filler:
Test Wall Perimeter Sealant:

Source chamber: Chamber C, Receiving chamber: Chamber A . Test specimen installed by client. Curing time:
Computer files: Lsrc: Lrec: Rtrec:

Area *S* of test specimen: 17.60 m^2
Mass per unit area: 0.00 kg/m^2
Air temp in the test rooms: °C
Air humidity in test rooms: %
Source room volume: 208 m^3
Receiving room volume: 52 m^3

Frequency *f* Hz	*R* One-third octave dB
50	> 26.15
63	> 38.25
80	> 42
100	**> 46.6**
125	**> 54.75**
160	**> 48.05**
200	**> 46.45**
250	**> 47.4**
315	**> 48.5**
400	**> 57.95**
500	**> 58.7**
630	**> 58.25**
800	**> 63.2**
1000	**> 65.85**
1250	**> 63.7**
1600	**> 64.7**
2000	**> 65.25**
2500	**> 66.1**
3150	**> 71.35**
4000	**> 75**
5000	> 80.4

Notes: 1. #N/A = Value not available.
2. **Bold** values are used to calculate STC and R_w.
3. Words in ***Blue Italic*** in the description are manufacturers brand names.



Rating according to ISO 717-1 **R_w (C;C_{tr}) = 61 (-2 ; -5) dB**

$C_{50\text{-}3150}$ = -3 dB $C_{tr,\ 50\text{-}3150}$ = -12 dB
$C_{50\text{-}5000}$ = -2 dB $C_{tr,\ 50\text{-}5000}$ = -12 dB
$C_{100\text{-}5000}$ = -1 dB $C_{tr,100\text{-}5000}$ = -5 dB

Rating according to ASTM E413 -87
Sound Transmission Class = 60 dB

No. of test report: **T0XXX** Name of test institute: University of Auckland Acoustics Testing Service.
Signature: Date:

Figure 4. The 1/3rd octave band values of airborne sound insulation – which are a theoretical prediction (with correction factors) – from the measured values of normalised impact sound pressure levels. Also shown are the single figure ratings STC and Rw.

2.2.2 Performance requirements

Unlike wall partitions, floor constructions have a dual insulation role in buildings – to insulate against structure borne sound and also against airborne sound. There are performance requirements specified in the NZ Building Code for each of these. For a floor-ceiling system to be successful it must meet these requirements as well as proving attractive structurally, economically and for serviceability (i.e. buildability and maintenance).

2.2.3 Obtaining the insulation performances

The Tamaki test facility is only suitable for testing the structure borne or impact sound insulation. For conventional flooring systems this is not a serious limitation as we have modelling software which allows us to predict the acceptability of airborne insulation, provided the performance is not borderline. Innovative floor developments have more complexity than a basic double-leaf structure like the prototype pole floor and the airborne insulation must be verified by measurement.

In this case, the airborne insulation could not be measured directly. Other research currently being carried out in the ARC proposes a technique for relating structure borne and airborne performance of floors so that one can be predicted from a measurement of the other. The purpose of this approach is to make screening checks on buildings easier by obviating the need to make both types of measurement. The airborne insulation result shown below has been obtained by this technique and is therefore a prediction from the measured impact sound insulation and should be regarded as tentative (details of the technique will be published later) .

2.2.4 Objective findings

The results for both forms of insulation show that the performance meets the requirements of the current NZ Building Code – the results of STC 60 and IIC 55 compare with the minimum performance requirements of both STC and IIC 55. Figures 3 and 4 show the detailed 1/3rd octave band results and the single figure performance values, STC, Rw, IIC and Ln,w .

It is important to note, however, that these results are for the uncovered, bare floor. One of the challenges that we face from the current fashion for uncarpeted rooms is to meet the impact insulation requirements with hard surfaces. The prototype floor meets the code functional requirement without any covering and – as with other flooring systems – will attenuate impact sound even better if carpeted

3. CONCLUSIONS

The overall aim of this line of research is to develop an easily transportable system for building six storey commercial buildings using Radiata for the main structural elements. This paper reports on a floor arrangement, with pole joists, that has acceptable sound-proof properties.

The objective acoustic testing of the prototype floor, using Radiata pole joists, meets all the acoustical requirements of the NZ Building Code when it is not carpeted. This is an excellent result for a hard surface flooring system.

The construction incorporates features identified in previous research as maximising the insulation from a given mass of lightweight flooring and hence we expect that the subjective acceptability will be at least as high as the best performing construction in that research. The ARC has been a strong critic of the NZ Building Code for expressing the performance requirements in terms of the US rating system. This system was formulated a half century ago and ignores the low frequency range which has become a dominant factor for light timber frame buildings in this era of high-power, wide-bandwidth home entertainment systems. In the absence of low frequency acceptability criteria – and especially for light timber framed structures – we have argued that subjective testing and comparisons with concrete-slab based floor systems are necessary.

Another pleasing feature of the pole floor is that it appears to be of a similar cost to the equivalent prestressed concrete floor. The cost is helped by the pole joists which are $18 per sq.m. cheaper than engineered I joists.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

[1] Chung, H., Emms, G., McGunnigle, K., Dodd, G. 'Improving the impact insulation of light timber floors', *First Australasian Acoustical Societies Conference, Noise of Progress*, *Proceedings of 1st Joint Australasian Acoustical Conference*, *Christchurch, New Zealand*, *November 20-22, 2006*, 2006

[2] Dodd, G., Emms, G., McGunnigle, K., Schmid, G. 'Findings from Listening to Impacts on Floors', *New Zealand Acoustics*, *19*, *(3)*, p17-24, 2006

[3] Dodd, G., Schmid, G., Emms, G. 'Subjective Assessment of the Impact Sound Insulation of LTF Floor-Ceiling Systems', *9th Western Pacific Acoustics Conference*, *Proceedings of WESPAC IX 2006*, *Seoul, Korea*, *June 26-28, 2006*, 2006

[4] Chapman, J.B. 'Can pinus radiata pole floor beams and joists make useful floors for multi-storey building?' *ANZAScA 41st Annual Conference*, Deekin University, Geelong, November, 14-16, 2007, pp 54-60.

[5] IMO (2005) International Shipping: carrier of world trade International Maritime Organisation, London, p.3

[6] http://astro.berkeley.edu/~wright/fuel_energy.html

[7] Luther, M.B., Moreschini, L., Pallot, P. 'Revisiting prefabricated Building Systems for the Future.' *ANZAScA 41st Annual Conference*, Deekin University, Geelong, November, 14-16, 2007, pp 157-164.

[8] NZS 3603: 1993. *Timber structures standard.* Standards Association of New Zealand.

Portal Frame Seminar

June 2010

This one-day technical seminar will focus on LVL and gluelaminated timber member design and alternative options of forming key connections in these large-span structures. Design examples will be covered and references will be made to the various sources of design information available to designers.

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