Improved Sound Insulated Floors for a Six Storey Timber Building System

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Summary

The overall aim of our research is to eventually develop a viable system, using pinus radiata, for demountable multi-storey timber buildings up to 6 storeys with sound insulating floors. The components are to pack efficiently into containers and be easily transported. This paper describes the proposed demountable multi-storey timber building system. Also, it reports on the testing of a prototype floor, with radiata pole joists, for sound insulation properties. Measurements have been made of the objective performance and complemented by subjective comparisons made in a purpose-built International Electro-technical Commission listening room. The results indicate that the floor meets code requirements – **even when it has a hard surface.**

Introduction

A worldwide interest in multistorey timber buildings is expected due to the environmental advantages of timber construction when compared to concrete and steel. Because New Zealand has a small population of 4 million and is a geographically isolated country, a healthy industry in manufacturing multi-storey timber buildings would rely on exporting.

A structural system for 6 storey timber commercial buildings is proposed in this paper. To achieve simple site erection, the elements are to be mechanically fixed, which means the buildings would be demountable. The main structural elements have rectangular sections and are mainly around 6m in length, which makes them suitable for efficient transport by 20 feet long containers.

The second part of the paper reports on a prototype floor, which incorporates findings from recent research undertaken at the Acoustics Research Centre of the University of Auckland. This 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 lightweight 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 - depending on the impact source - than the reference concrete floor used for comparison [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/m2 [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, - which is that the floor’s overall response to sound and peaks in its frequency response will be reduced.

Proposed Structural System, 6 Storey Commercial Timber Buildings

The 6 storey commercial timber building system is illustrated in figure 1. The main structural elements are columns and beams, which are pin jointed together, and rely on diagonal braces to support horizontal wind and earthquake loads. This structural system results in minimum bending moments in the main members, which reduces their sizes and suits the theme of a demountable and easily transportable building.

The column elements are fabricated from 63mm thick LVL. The LVL column elements are placed in pairs and stabilised by 315mm wide * 45mm thick LVL ‘column stabilising’ members, placed at right angles to them. The columns have a factor of safety of around 2.0 and do not rely on the stabilising column elements to support vertical load. The column stability members will be mechanically fixed on site to the column elements and will assist supporting secondary moments in the columns. Both the column and column stability elements are around 10.3m long and require jointing around the 3rd floor level.

The main floor support beams are 600mm deep * 63mm thick LVL elements and are located in the same plane as the columns elements. They will need to be ‘reinforced’ at the ends where they bear on the columns, to prevent side grain crushing. The flooring is attached to the top of

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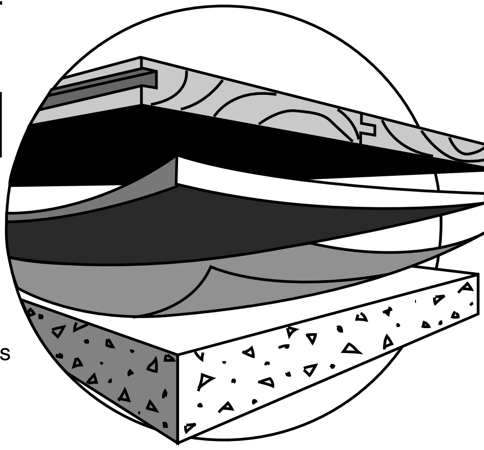
FLOOR ISOLATION



TYPICAL PERFORMANCE CHARACTERISTICS

The table below gives IIC ratings based on tests of various surface treatments Ref. ASTM E989 using an Impactamat resilient interface on a 100mm thick concrete structural floor.

FLOOR SURFACE TREATMENT (Floating Floor Construction)	Impactamat			Overall IIC Rating	IIC Improvement over bare slab	Ref.fig.
	Construction	Type	Thickness			
Loose lay timber veneer flooring with thin foam bedding layer	full cover	750	5mm	47-50	18-20	1
Direct bond 19mm block parquetry	full cover	900	5mm	45-49	18-20	2
Direct bond 10mm ceramic tiles	full cover	750	5mm	44-46	13-15	2
Particle board or strip timber battens supported at nom. 450 x 450 centres with acoustic absorption	pads 75 x 50mm	750	10mm	52-60	21-30	3
Double layer bonded 12mm ply with bonded parquetry, supported at nom. 300 x 300 centres (sports floor)	pads 75 x 50mm	750	10mm	52-57	21-27	4
50mm reinforced concrete slab or 25 mm slab with 20mm bonded marble/slate/ceramic tile	full cover	750	10mm	58-63	27-32	6
50mm reinforced concrete slab	full cover	750	15mm	59-64	28-33	5
100mm reinforced concrete slab	full cover	750	15mm	60-65	29-34	5

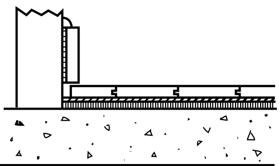


Fig. 1 Timber loose lay floating floor

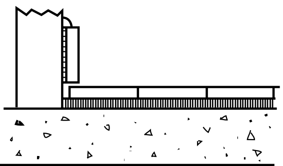


Fig. 2 Direct bond parquetry or ceramic tiles

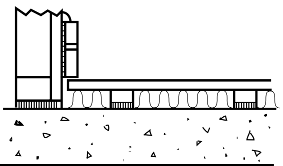


Fig. 3 Timber strip floor on battens with isolated frame wall

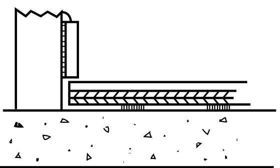


Fig. 4 Sports floor

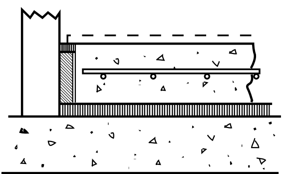


Fig. 5 Concrete slab

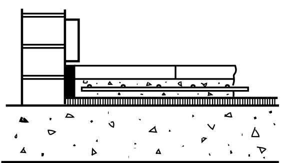


Fig. 6 Marble/slate ceramic tiles with thin reinforced slab

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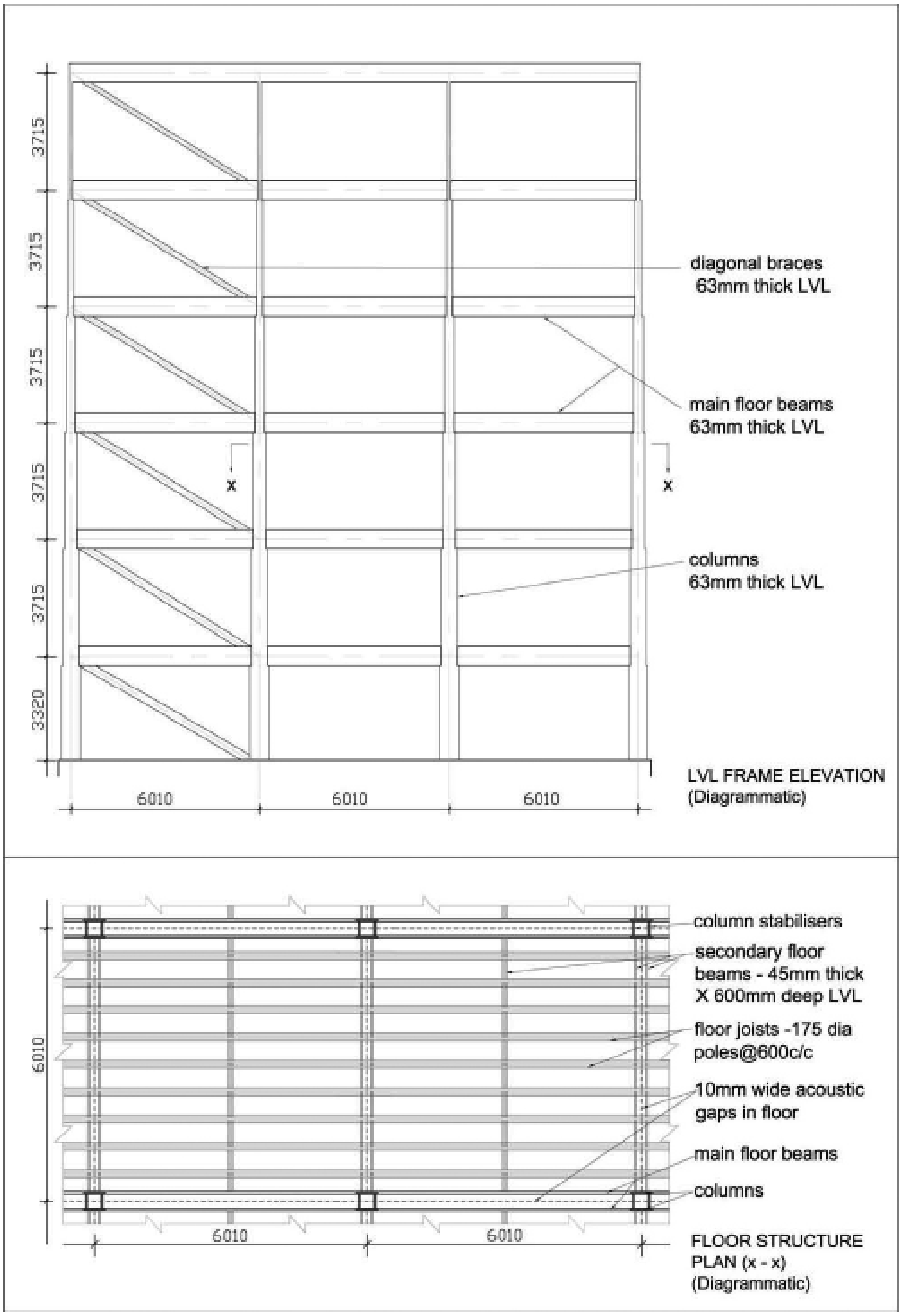


Figure 1: Proposed Structure System for 6 Storey Timber Commercial Building

the beams and stabilises the beam compression region.

The secondary floor beams are effectively pairs of 600mm deep * 45mm thick LVL elements at 3.005m centres. They have 175mm * 175mm portions cut out at 600mm centres to receive the floor joists, and are shear keyed to the flooring to achieve composite action.

The joists are 175mm small end diameter pinus radiata poles, 6m in length, that are 4 sided with opposite faces 175mm apart. They are continuous over 2 spans and there is a 10mm 'acoustic gap' between the ends of the joists. The poles provide mass to assist floor sound proofing, and are more economic than engineered 'I' joists.

The proposed lateral load resisting system is shown in figure 1. It is a vertical cantilever truss with singly braced bays. The diagonal braces are 63mm thick LVL in the same plane as the main frame and vary in depth from 275mm at level 1 to 150mm at level 6. This arrangement is convenient for fixing mechanically on site. It has architectural challenges because of interruptions to the floor space but has advantages over shear walls or cross bracing because more area is available for windows on external walls; and internal doors can be located under braces. For earthquake prone regions, the steel cleats connecting the ends of the bracing members to the main frame could be appropriately 'necked' so as to yield and absorb earthquake energy.

The prefabricated flooring elements are 6m long, 1.2m wide, and 95mm thick as described in figure 6. Each 6m * 6m section of floor is separated from adjacent floor sections with a 10mm wide 'acoustic gap'. The discontinuity of the flooring will reduce sound transference and, also, prevent secondary moments from being generated in the columns.

We have deduced that the components of the proposed prototype building, as shown in figure 1, including column members, beams, joists, floor panels, 125mm thick external wall panels, pack into 11no. 20 feet and 3 no. 40 feet containers. Transporting containers by sea is efficient and its environmental impact is minimal. A container ship uses 0.12MJ per tonne¬km, whereas road freight uses 2.8 MJ per tonne-km [5] [6]. Prefabricated buildings are more viable due to 'mass custom' options made available by computer controlled milling machines. Modular systems can be easily modified to offer considerable diversity. Other advantages of prefabricated buildings include low cost, compact shipping, factory quality controls, and material waste reduction [7].

Prototype Floor with Pole Joists for Acoustic Testing

A test floor of approximately 50 sq.m. was constructed with 200mm dia. radiata pole joists @ 600mm centres as per figures 2 & 4. Timber floors previously developed by a team that included the Acoustic Research Centre informed the design of the flooring and ceiling components. The main difference is that this test floor used timber pole joists, and the previous floors used engineered 'I' joists. The tapered poles have two opposite faces cut at 205mm apart to provide consistent depth and flat surfaces

Figure 2, Floor test rig, 200 small Figure 3, Floor Test Rig, End dia. poles @ 600mm centres Measuring the sound field

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 CO2 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.

One of the main issues for timber floors is that they are more expensive than an equivalent pre-stressed concrete system. 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, which results in a floor cost difference of $20/m2 [4].

Research into the Insulation Against Sound of the Prototype Floor System.

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 rig and the floor as built are shown in Figures 2, 3 & 4.)

The test facility – whilst not part of the Acoustic Research Service's suite of ISO chambers of reverberation chambers with suppressed flanking transmission – meets the requirements for laboratory testing (according to ISO 140) of the impact insulation of floors. Figures 2 & 3 show the floor-test facility with the prototype floor in place; Figure 3, 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 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

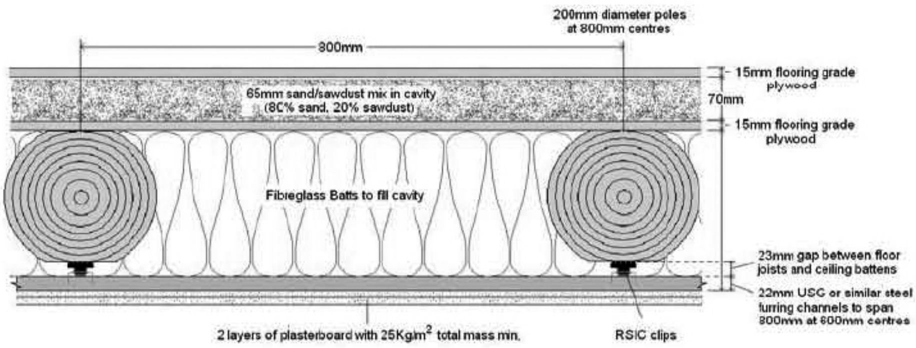
Description and identification of the test specimen and test arrangement: Client: University of Auckland

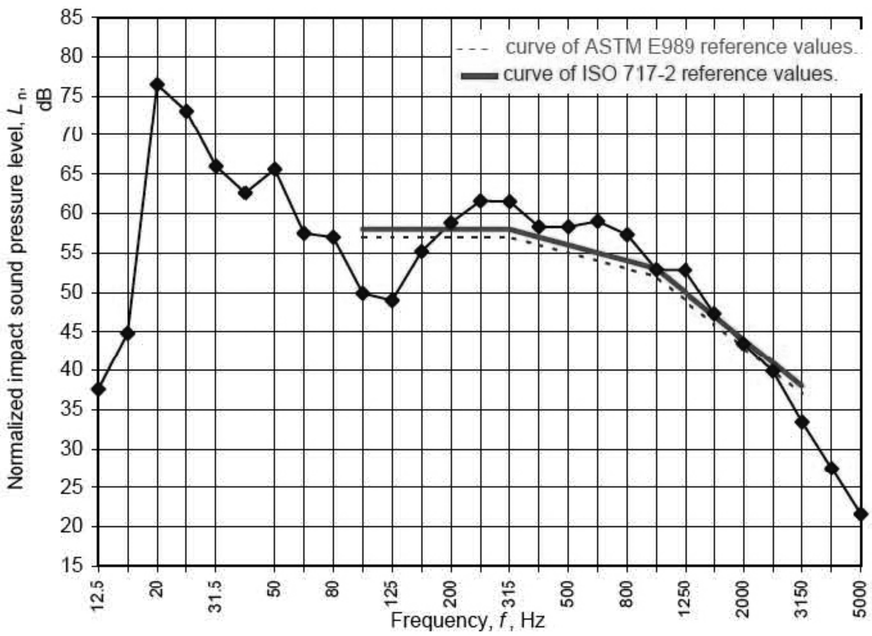
A light weight timber floor/ceiling system comprising: 15mm butt jointed plywood sheets 2700mm x 1200mm fixed with 40mm square head screws at 150mm centres onto 70mm x 45mm battens 45mm side down at 450mm centres angle screwed to 15mm but jointed plywood sheets 2700mm x 1200mm fixed with 50mm square 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

SECTION FIGURE 1. **Typical section across joists**





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 4. 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

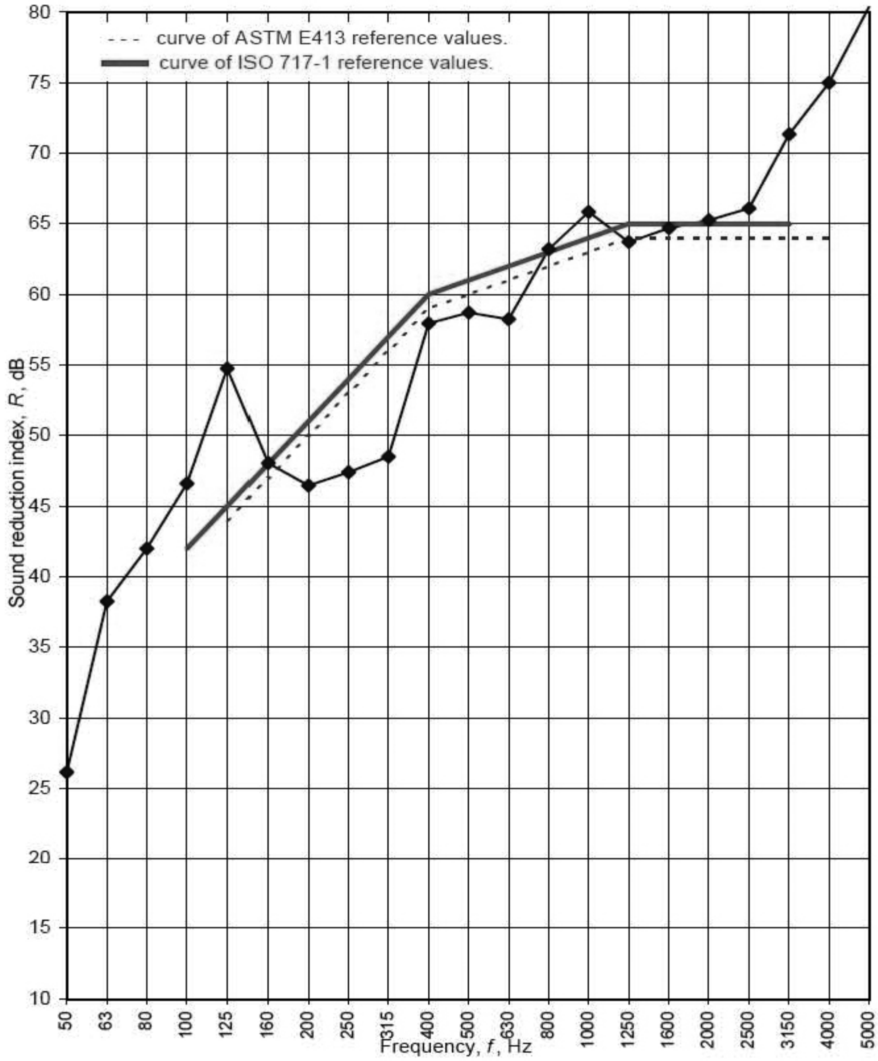
Description and identification of the test specimen and test arrangement: Date of test:
Airborne sound insulation of a Double leaf single frame wall Client:
Test Wall Frame:
Test Wall Linings: Source chamber side:
Receiving chamber side:
Cavity Absorption:
Test Wall Lining Joint Filler:
Test Wall Perimeter 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: ^oC
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 5. 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.

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, and 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).

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 predict the acceptability of airborne insulation, provided the performance is not borderline. For innovative floor developments which, as for the prototype pole floor, have more complexity than a basic double-leaf structure, the airborne insulation must be verified by measurement. In this case, as the airborne insulation could not be measured directly, we applied findings from other research currently being carried out in the University of Auckland in which we are proposing a technique for relating structure borne and airborne performance of floors so 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 (details of the technique will be published later) and it is a result which should be regarded as tentative..

Objective findings

The results for both forms of insulation show that the performance is predicted to meet 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 6 and 7 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.

Conclusions

The overall aim of this line of research is to develop an easily transportable system for building 6 storey commercial buildings using radiata radiata as the main structural elements. This paper reports on 2 aspects of this study. The 1st describes the proposed arrangement of the structural members; and the 2nd is a floor arrangement, with pole joists, that has acceptable sound-proof properties.

Because the structural components are either planks of LVL or 4 sided round timber, and their lengths are typically 6m , or slightly less, they pack efficiently in 20 feet long containers. Transport by sea has minimal environmental impact with container ships using 0.12MJ per tonne-km. Modern computer controlled machinery allows modular building systems to be easily modified resulting in diversity.

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.

Verification of this by means of subjective comparisons is in progress. 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.

Acknowledgements

The assistance of Gian Schmid (ATS Test Officer) and Ming Li (Doctoral student) is gratefully acknowledged. Without their help the testing would not have been possible. We also thank Dr Robert Vale for assisting us with the energy requirements for transporting.

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