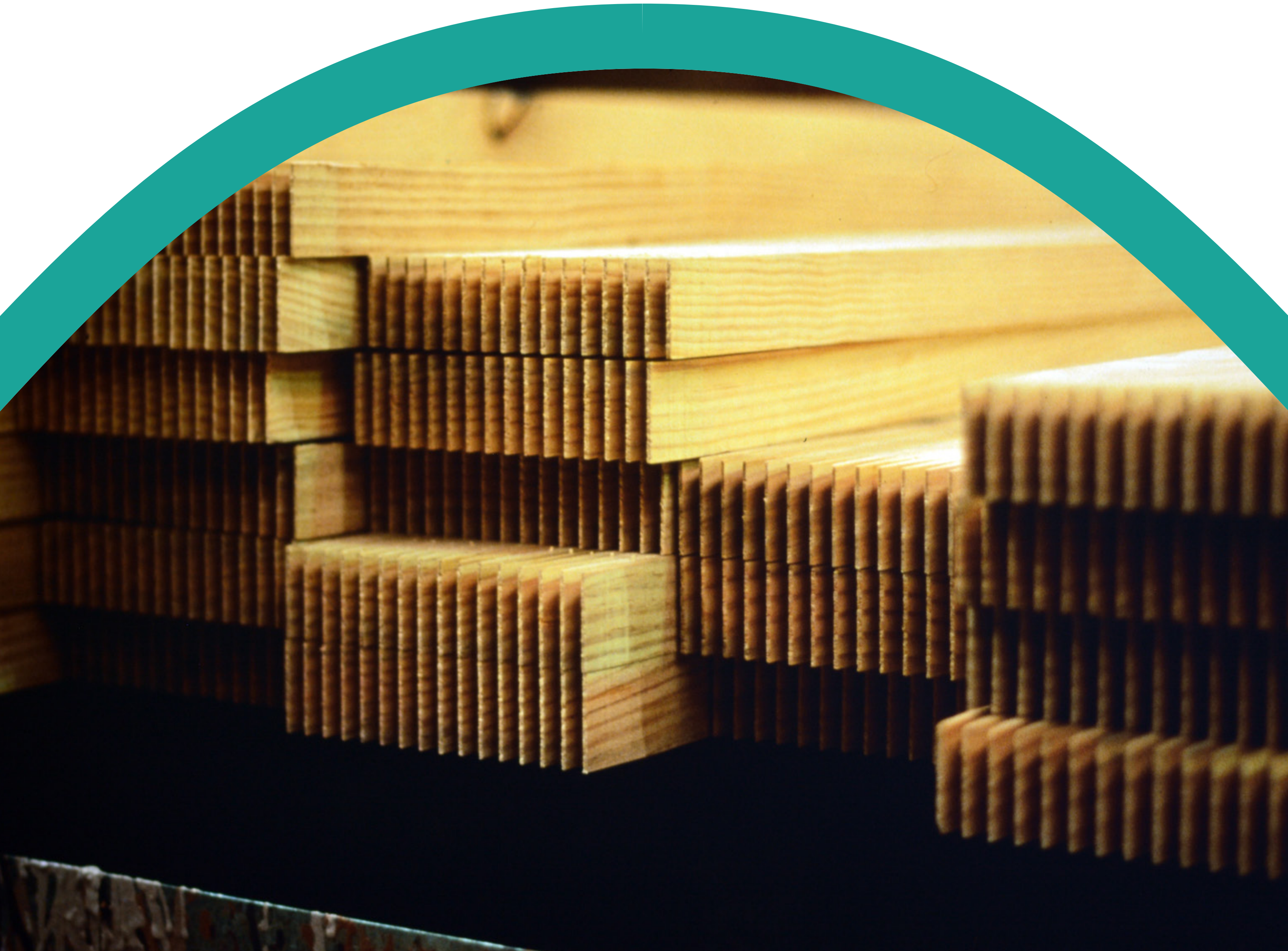
Final Report
Project NV057

NATIONAL INSTITUTE FOR
FOREST PRODUCTS INNOVATION

Fire, acoustic and structural performance of prefabricated plantation Shining Gum advanced timber composite (ATC) floor systems

2024



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NATIONAL INSTITUTE FOR
FOREST PRODUCTS INNOVATION
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Fire, Acoustic and Structural Performance of Prefabricated Plantation Shining Gum Advanced Timber Composite (ATC) Floor Systems

Prepared for

National Institute for Forest Products Innovation

Gippsland

by

TPC Solutions (Aust) Pty Ltd

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Australian Government
Department of Agriculture, Fisheries and Forestry

VICTORIA State Government

1. Executive Summary

The use of Gippsland hardwood as a solid timber structural member has been limited to commodity products due to the limitation in length, size, and performance of traditional sawn timber members. The advent of glue-laminating technology enables the manufacture of large end section, glued laminated timber (glulam) products with enhanced product length, size, and performance. The use of cutting-edge CNC (computer numerical control) machinery now used in industry also enables intricate, millimetre perfect detailing of cuts, mitres, and connections to be made in these large cross-section, mass timber elements.

A shift to these engineered timber products (e.g., glulam) provides the opportunity to utilise the inherent strength properties of the hardwood fibre resource together with high technology processing to produce high strength, uniform, and resource efficient products. Glulam mass timber products have the potential to efficiently utilise the plantation shining gum (*Eucalyptus nitens*) hardwood resource and using material which may previously have been used in low structural grade applications.

This research project undertook a series of full-scale tests to investigate and develop, an innovative mass Advanced Timber Composite (ATC) Floor System that can be used in multi-storey buildings utilising the plantation shining gum (*Eucalyptus nitens*) timber resource sourced from the Gippsland region. The series of tests investigated the performance of the ATC Floor System in relation to:

- Structural connector capacity of various shear key types that can be used in the fabrication of the ATC Floor System
- Structural performance of loadbearing glued laminated shining gum timber beams
- Fire performance of a loadbearing glued laminated shining gum ATC Floor System
- The effect of fire on the structural capacity of steel connections to support the ATC floor system, and
- The acoustic performance of the ATC Floor System.

The full-scale testing demonstrated that the plantation shining gum resource, in combination with glue-laminated technology, can be designed and fabricated into large glulam members and used in an advanced floor system to achieve the required structural, fire and acoustic performance in compliance with the National Construction Code 2022 (Building Code of Australia Volume One) for use in apartment and office type buildings.

The availability of a plantation hardwood shining gum resource provides industry with opportunities of utilising a comparatively strong, dense and available resource in the manufacture of innovative timber building systems. These building systems are highly desired by Architects, developers and other building professionals to visually expose the mass timber elements and provide a marketplace point of difference compared to traditional forms of construction.

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2. Introduction

There is a growing market demand for large spanning timber systems for use in mid-rise multi-storey building developments such as apartments and offices. Some of the key drivers for this demand is the desire of building designers to use environmentally friendly building products such as timber, as well as structurally efficient and fire effective engineered timber building systems.

The use of Gippsland hardwood in solid timber structural members has traditionally been limited to “commodity” products due to the limitations in length, size, and performance of sawn timber members. However, the use of glue-laminating technology enables the manufacture of large sized structural glued laminated timber (glulam) products of much larger depth, breadth, length, and performance. Additionally, the use of state-of-the-art CNC (computer numerical control) machinery also enables intricate, millimetre perfect detailing of cuts, mitres, and connections to be made.

In modern multi-storey timber buildings, one option for the floor system can involve the use of Timber Concrete Composite (TCC) elements, which in comparison to traditional floor systems, provides an improved vibrational performance and acoustic separation, increased overall system stiffness, fire resistance, and good thermal mass.

This report describes the activities undertaken in investigating the development, testing and validation of design methodologies for an innovative floor system, using the plantation shining gum (*Eucalyptus nitens*) resource from the Gippsland region, to deliver a large span, acoustically quiet, and fire-rated advanced timber composite (ATC) floor system to comply with the National Construction Code 2022 (NCC) building provisions and market demands.

The NCC sets the minimum performance requirements for new buildings in relation to health (including acoustic performance) and safety (including structural and fire performance), as well as other design considerations. This project undertook specific testing to address the key NCC provisions that directly relate to floor systems; these being–

- Acoustic performance – Airborne and impact sound
- Structural performance, and
- Fire performance – up to 120 minutes.

In Australia, some limited research has been undertaken on timber-concrete composite systems; however, none have utilised plantation shining gum or undertaken full-scale fire and acoustic system testing as undertaken in this project and detailed in this report.

3. Methodology

Full-sized Advanced Timber Composite (ATC) Floor System panels were specifically engineer designed, structural glued-laminated timber beams manufactured, ATC floor systems fabricated, and tests undertaken seeking to verify and demonstrate the key system performance requirements in relation to fire, structural capacity, and acoustic performance. The objective being to demonstrate compliance with the National Construction Code 2022, Building Code of Australia Volume One (NCC) provisions. The following steps were undertaken in meeting this objective.

3.1. ATC Floor System Design

A wholistic prefabricated design approach of the fabricated ATC Floor Systems considered the anticipated allowable floor loading (permanent and live loading), transportation requirements (e.g., panel width, panel weight, lifting arrangements, installation), fire resistance, and other relevant floor design criteria (e.g., vibration). The objective was to design the panels for use in non-domestic type buildings such as residential apartments (Class 2) through to offices (Class 5).

3.2. ATC Floor System Fabrication

The ATC Floor System panels were fabricated off-site by TGA Engineers and incorporated both Victorian ash (benchmark) and plantation shining gum hardwood glulam floor joists, plywood formwork (where specified), steel shear connectors, and a concrete screed with steel mesh reinforcement – refer Figure 1.

During fabrication *Finished panels*

Figure 1 – ATC Floor System Components

Photos: Robert Nestic (TGA Engineers)

Two ATC Floor System panels were fabricated for fire testing (refer Figure 1) and a further panel was fabricated and used for both acoustic and structural load testing in order to determine the sound insulation performance, and structural capacity and serviceability performance respectively of the designed floor system. The fabricated ATC Floor System panels were then delivered to the accredited testing facilities for testing.

3.3. Glued-laminated Timber Beams

Victorian hardwood glued-laminated timber beams (glulam) were manufactured by Australian Sustainable Hardwoods (ASH) to their MASSLAM manufacturing specifications. These glulam beams were manufactured in both plantation shining gum and Victorian ash; with the latter used to benchmark the structural and fire resistance test results. Based on the ATC floor System design, the glulam beams were sized, docked and CNC machined to the required cross-sectional dimensions, length, and profile.

3.4. Fire Performance

The key objective of the fire performance testing was to demonstrate, and confirm, the ability of the ATC Floor Systems to achieve a fire resistance level (FRL) of FRL 120/120/120 *[structural adequacy / integrity / insulation]*. The floor system was designed considering the typical loading that would occur in buildings where the floor system would be used (e.g., apartment and office buildings).

The designed ATC Floor System was then tested at Warringtonfire Australia, an Accredited Testing Laboratory, as a loadbearing system in accordance with the requirements of AS 1530.4-2014 *Methods for fire tests on building materials, components, and structures - Fire-resistance tests for elements of construction.* The loadbearing fire characteristics of the floor system was measured during the fire resistance test and a post-test evaluation undertaken. Following completion of the testing, a test/assessment report has been prepared suitable for use in the marketplace as evidence of compliance.

3.5. Acoustic Performance

A full-scale ATC Floor System panel was fabricated on which to undertake acoustic insulation performance testing by CSIRO as described in Section 4.3.1 of this report. The testing considered various floor surface acoustic treatments as well as a suspended ceiling attached to the underside of the floor system. The testing undertaken considered both airborne as well as impact noise. It should be noted that this type of full-scale timber floor system acoustic testing is a major project initiative and has typically not been undertaken elsewhere due to time, cost, and planning constraints.

Reports for each of the tested systems were prepared by CSIRO and described in Section 4.3.2 of this report. The CSIRO test results were then used to calibrate the INSUL® software package developed by Marshall Day Acoustics. INSUL® is a software modelling program developed for predicting the sound insulation of walls, floors, ceilings, and windows and can be used to develop performance estimates of these construction elements.

3.6. Structural Performance

The ATC Floor Systems were designed and fabricated by TGA Engineers using MASSLAM timber members manufactured by Australian Sustainable Hardwoods. The structural engineering designs of the ATC Floor Systems were undertaken using an Excel spreadsheet developed by TGA Engineers. This spreadsheet utilises the Eurocode 5 Part 1-1 method (Annex B) for calculating shear connector loads for mechanically jointed beams as given in Eurocode 5 (CEN, 2003a) and the design of timber-to-concrete connections guided by Eurocode 5 Part 2 (CEN, 2003b) and adapted for use in Australia to comply with design in accordance with AS 1720.1 (2010).

Various shear connection types, sizes and configurations were considered and modelled using the developed spreadsheet to determine the appropriate system lay-up for the specific test being undertaken i.e., structural capacity, fire resistance.

4. Test Program

The following describes the test program undertaken to determine the structural, fire and acoustic performance of the proposed plantation shining gum (*E. nitens*) ATC Floor System.

4.1. Structural Design

The composite structural performance of the ATC Floor System is essentially governed by the interaction between the reinforced concrete slab floor and the structural glulam beams via steel shear connectors enabling composite action – refer Figure 2.

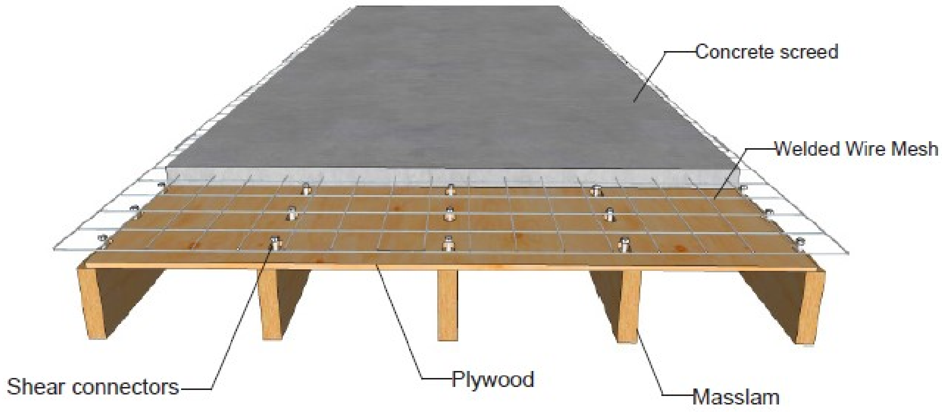


Figure 2 – ATC Floor System Components

This composite action takes advantage of the compressive strength of concrete, used as the top floor slab surface, and the tensile strength of the timber floor joists used to support the concrete, and working in composite with the concrete floor slab to span the required distance.

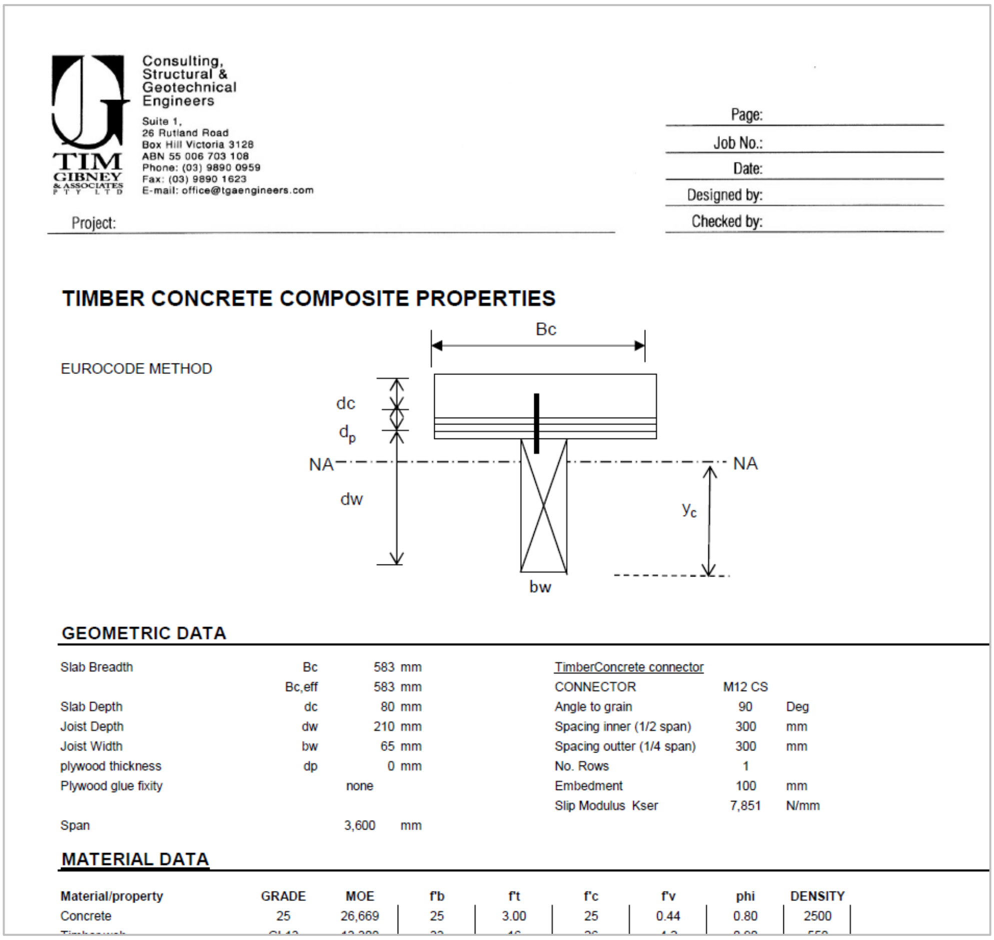
Note: The plywood introduced to support the installation of the concrete floor slab can be used to contribute to the effective stiffness of the combined system; however, it was not used in the calculation of the structural engineering section properties of the ATC floor system for this research project. The plywood was considered for the fire and, if present, acoustic performance of the system.

The combination of building materials, having different structural properties and different environmental/in-service behaviour, adds a level of complexity to design. Consideration must also be given to the fact that full composite action will not typically be achieved (e.g., slip between the elements) and must be accounted for.

The structural design of such a composite floor system is complex and requires simplification to enable modelling of the system to be undertaken. A modelling design simplification is provided in Eurocode 5 (EC5) which uses "Gamma coefficients" to account for the interaction between the concrete and timber components and this method has been used in this project for analysis and design purposes. This EC5 method has been modified to align with design practices in Australia e.g., loading standards and AS 1720.1 (timber design standard).

4.1.1. ATC Floor System – Engineering Design

An engineering design Excel spreadsheet was developed by TGA Engineers to enable the rapid design and evaluation of proposed full-scale ATC test floor systems as described in section 4.1. The test panels were designed for the specific test spans, loading requirements and objective of the test and therefore none of the panels were identical.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TIMBER CONCRETE COMPOSITE PROPERTIES

EUROCODE METHOD

GEOMETRIC DATA

Slab Breadth	Bc	583 mm	TimberConcrete connector		
	Bc,eff	583 mm	CONNECTOR	M12 CS	
Slab Depth	dc	80 mm	Angle to grain	90	Deg
Joist Depth	dw	210 mm	Spacing inner (1/2 span)	300	mm
Joist Width	bw	65 mm	Spacing outter (1/4 span)	300	mm
plywood thickness	dp	0 mm	No. Rows	1	
Plywood glue fixity		none	Embedment	100	mm
			Slip Modulus Kser	7,851	N/mm
Span		3,600 mm			

MATERIAL DATA

Material/property	GRADE	MOE	f'b	f't	f'c	f'v	phi	DENSITY
Concrete	25	26,669	25	3.00	25	0.44	0.80	2500

Figure 3 – Excel Spreadsheet

The design spreadsheet (refer Figure 3) enabled TGA Engineers to select, and check, various ATC Floor System configurations for the required application being considered, such as:

- System Geometry
  - slab thickness
  - timber floor joists (size, spacing)
  - plywood thickness (if used)
- Timber-Concrete Connector
  - type
  - connector angle to grain
  - connector spacing
  - rows
  - embedment depth etc.
- Material Data
  - concrete strength
  - timber floor joists properties
  - plywood properties (if used)

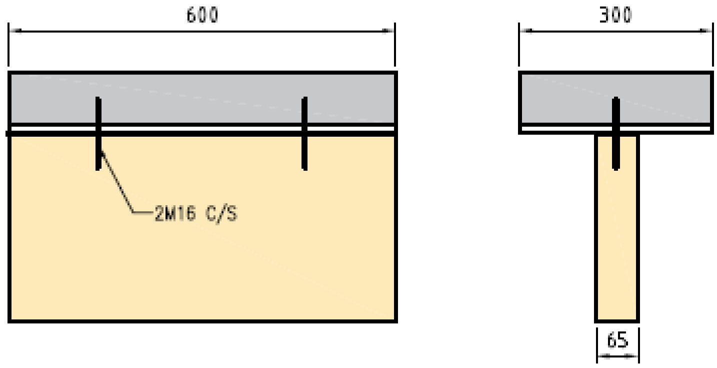
The spreadsheet allows the engineer to input the imposed design loads (i.e., live loads) that need to be designed for and the spreadsheet calculates the performance of the timber-concrete composite floor system for serviceability (short and long-term deflection) and strength ultimate limit states for the individual ATC floor system components: concrete, shear connectors and timber. The spreadsheet also considers the dynamic performance of the floor system which may be critical in the design of large spanning floor systems.

Using the spreadsheet, full-sized ATC Floor Systems were designed and fabricated on which structural beam (refer Section 4.1.3), fire (refer Section 4.2.2) and acoustic (refer Section 4.3.1) performance testing was then undertaken.

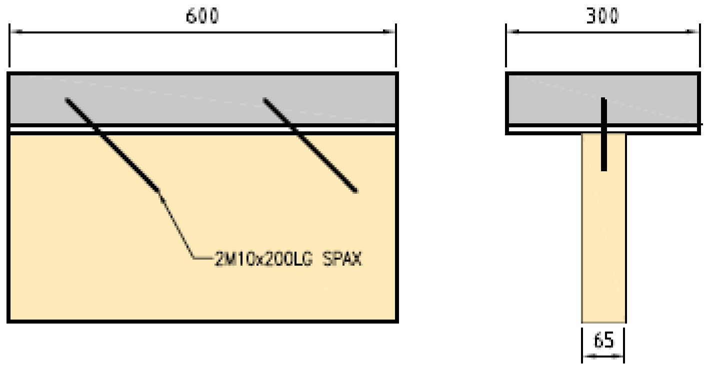
4.1.2. Shear Connector Tests

A number of shear connector types were proposed, based on simplicity, capacity and innovation, and were physically tested. The connection types investigated were:

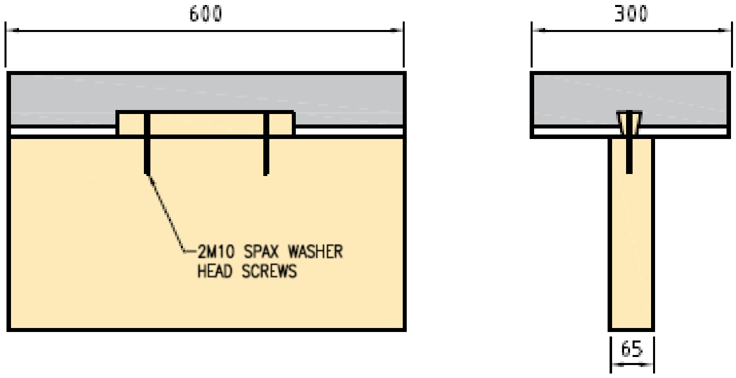
1. Type A – Vertical M16 coach screws, 100 mm embedment, 50 mm projection in concrete at 200 mm centres along the top edge of the glulam beam



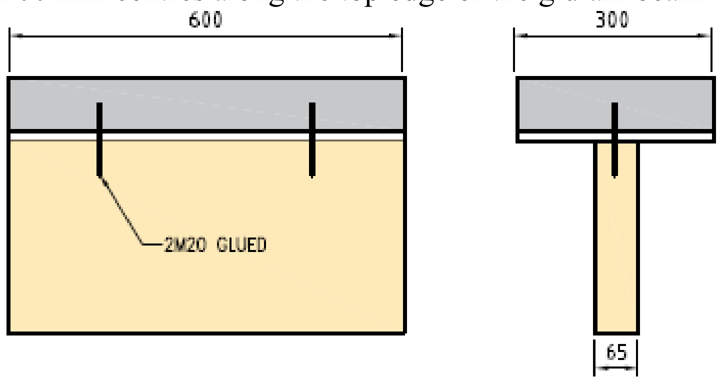
2. Type B – 45 degree inclined M10 x 200 mm SPAX full-thread screws at 200 mm centres along the top edge of the glulam beam



3. Type C – 2 x M10 SPAX washer head vertical screws at 200 mm centres in conjunction with a 50 x 20 mm timber block polyurethane glued along the top edge of the glulam beam



4. Type D – Vertical M20, Grade 4.6 bolts epoxy glued into a 22 mm diameter hole at 200 mm centres along the top edge of the glulam beam



Individual 300 mm wide x (approx.) 400 mm deep x 600 mm long 'T' section test specimens, with a concrete slab 60 mm thick, were fabricated using each of these shear connector types with the following interlayers (refer Figure 4):

1. No plywood
2. 15 mm plywood
3. 25 mm plywood

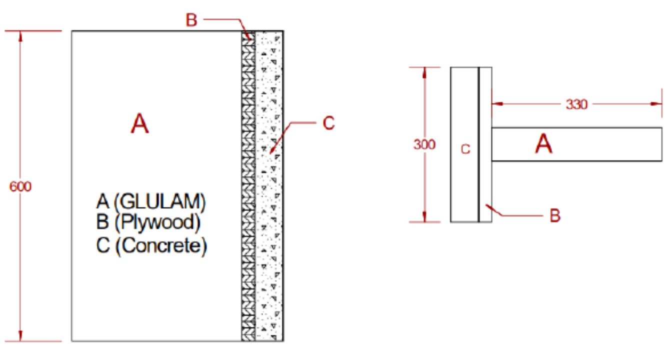


Figure 4 – Test Specimen Details

A test jig was designed by TGA Engineers (refer Figure 5) and fabricated by the test facility in which to undertake the shear connector tests. The test setup was instrumented to measure the load-displacement characteristics and the ultimate load capacity of the specimens.

The designed test jig performed extremely effectively and enabled testing to be undertaken quickly and efficiently.

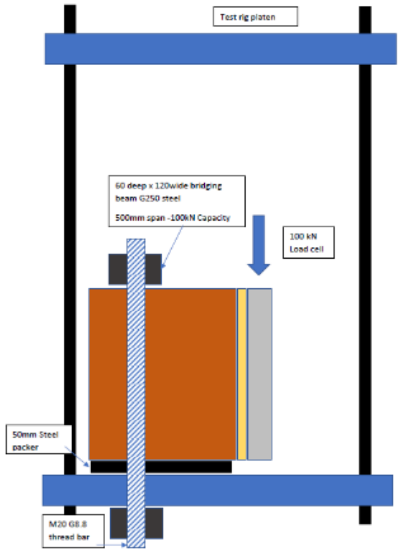


Figure 5 – Shear Connector Test Set-up

In total, 72 individual plantation shining gum and Victorian ash (benchmark tests) shear connector tests were undertaken.

All specimen types were tested using a 300 kN Universal Testing Machine with displacements measured using 2 transducers mounted onto the concrete. All sensors were independently calibrated and load-displacement data produced by the testing machine. The glulam component was supported on a 50 mm steel plate and clamped to the machine's platen with 2 pairs of M14 threaded bolts, the load was centrally applied to the concrete component, a 40 mm steel plate was placed on the concrete component to evenly spread the load (refer Figure 6). Some of the specimens tilted prior achieving the maximum failure load, which led to the removal of the deflection transducers. Manual digital dial gauges were fitted, and readings manually recorded.

Figure 6 – Shear Connector Test

During specimen tests, specimens were loaded to failure and documented (refer Table 1) and load-displacements measured and plotted (refer Figure 7).

Table 1 – Example: Test results for concrete and plantation shining gum glulam and 15 mm plywood for Type D shear connector

Construction type	Shear connector type	Specimen ID	Maximum load kN	Comments
Concrete & Shining Gum glulam with 15mm plywood	D	D-1	86.246	Concrete cracked.
		D-2	81.430	Concrete cracked.
		D-3	80.782	Concrete cracked.

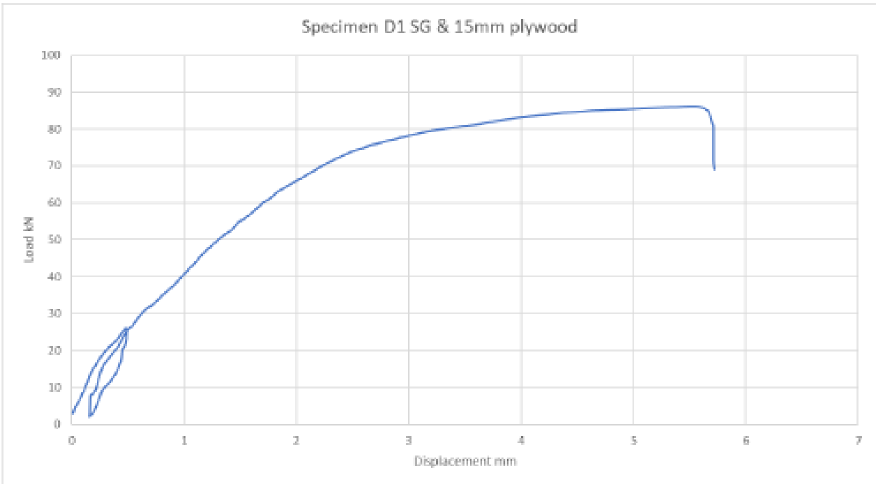


Figure 7 – Example: Load-displacement chart for concrete and plantation shining gum glulam with 15mm plywood for specimen D1

Each of the shear connector type tests provided an insight into the slip behaviour and ultimate capacity of the connection. It was evident that a dowel type connector exhibits a more ductile behaviour with varying degrees of ductility, compared to a rigidly screwed and glued in block of timber. It was decided, based on AS 1649 and AS 1720.1, to determine the connector stiffness at a slip of 0.5 mm and 2.5 mm. This is in line with Australian methodology and can directly be compared to joint stiffnesses determined in AS 1720.1 Appendix E. Typically, during design serviceability, load limits the displacement of joints between these bounds.

A summary of the analysed test results is provided in Table 2 with the mean shear connector strength and stiffness provided in Figure 8 and Figure 9 respectively.

Table 2 – Shear Connector Test Results

CONNECTION TYPE	PLYWOOD	SPECIMEN NO.	Fmax (kN)	MEAN (kN)	ks 0.5mm (N/mm)	MEAN (N/mm)	ks 2.5mm (N/mm)	MEAN (N/mm)
A	NO PLYWOOD	A1	42.75	39.27	19,129	16021	12,505	8648
		A2	43.72		13,896		6,220	
		A3	31.35		15,039		7,218	
	15MM PLYWOOD	A1	30.28	33.11	14,965	12394	8,642	7242
		A2	40.60		14,650		6,908	
		A3	28.44		7,566		6,177	
	25MM PLYWOOD	A1	46.11	32.23	9,500	9741	5,723	5543
		A2	25.28		10,331		5,621	
		A3	25.30		9,393		5,284	
B	NO PLYWOOD	B1	34.80	36.78	15855	14248	11917	12116
		B2	41.95		12378		12449	
		B3	33.60		14510		11983	
	15MM PLYWOOD	B1	33.18	30.59	5706	6861	8696	8213
		B2	28.67		7131		8159	
		B3	29.91		7747		7783	
	25MM PLYWOOD	B1	34.12	30.89	7599	6631	8823	6635
		B2	25.61		7768		6770	
		B3	32.95		4527		4313	
C	NO PLYWOOD	C1	28.11	29.17	9053	11567	7627	13290
		C2	28.97		8800		14148	
		C3	30.44		16848		18095	
	15MM PLYWOOD	C1	21.01	23.17	8882	13853	10231	12189
		C2	25.37		22337		14973	
		C3	23.14		10340		11362	
	25MM PLYWOOD	C1	27.03	24.40	6744	12863	9697	12196
		C2	20.17		13916		11615	
		C3	25.99		17928		15277	
D	NO PLYWOOD	D1	37.47	39.15	17626	17878	14084	14131
		D2	38.97		18347		14084	
		D3	41.03		17661		14224	
	15MM PLYWOOD	D1	43.13	41.41	25663	26153	14787	14396
		D2	40.72		31900		14598	
		D3	40.39		20896		13804	
	25MM PLYWOOD	D1	34.73	36.65	6695	9398	8479	9964
		D2	38.65		17102		12658	
		D3	36.57		4397		8756	

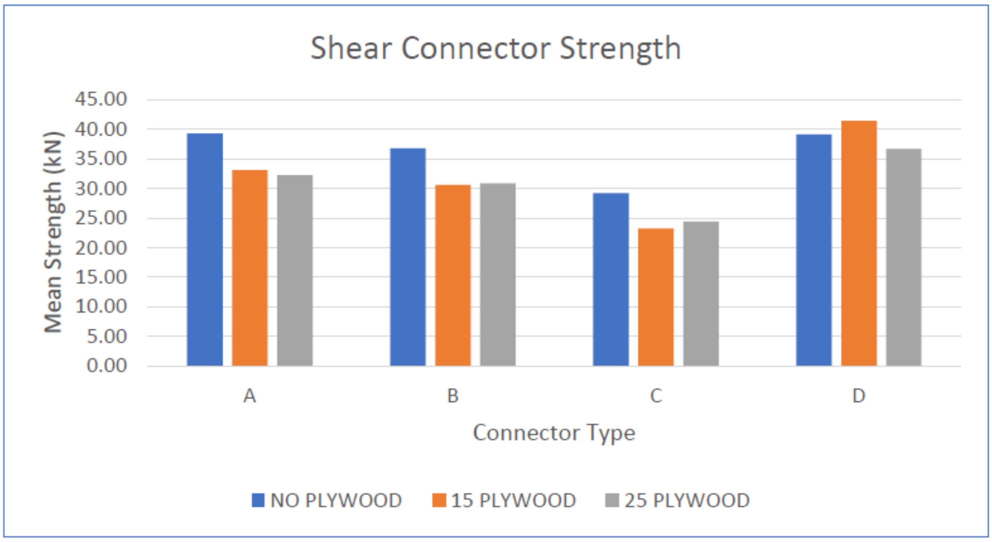


Figure 8 – Mean Shear Connector Type Strength

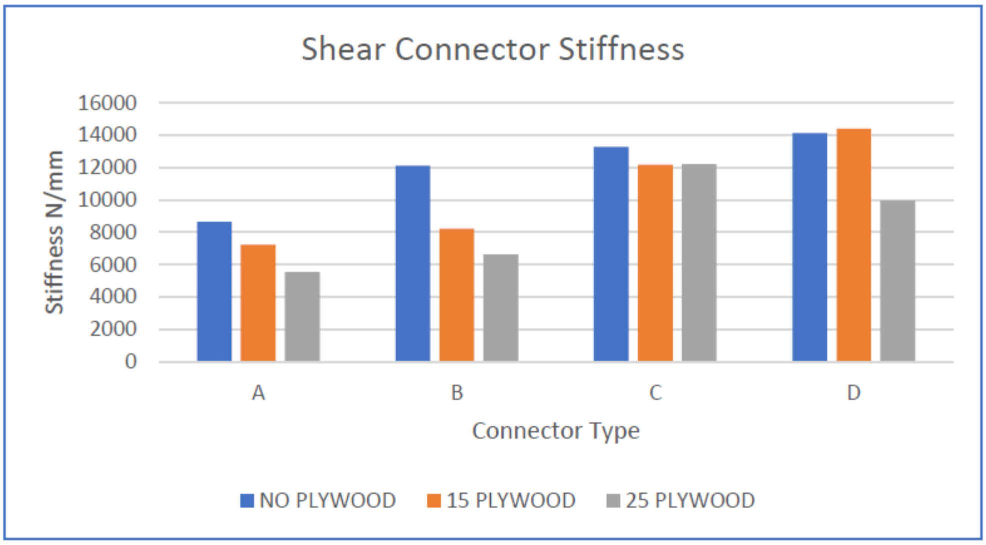


Figure 9 – Mean Shear Connector Type Stiffness

This indicative testing was undertaken to provide a degree of confidence in the engineering approach and properties used for the design of the ATC composite systems.

4.1.3. Full-scale ATC Beam Tests

Full-scale tests of ATC floor system plantation shining gum beams were undertaken following completion of the acoustic laboratory tests undertaken at CSIRO (Clayton) – refer Section 3.5. Four (4) T-Section beams were cut from the pre-fabricated acoustic floor panel system and used for the full-scale structural tests.

The T-Section test specimens comprised of a reinforced concrete slab flange, shear connectors and a finger jointed shining gum glulam beam (no plywood form present). The length of each specimen tested was 3600 mm, with the plantation shining gum glulam beam of a nominal (depth x breadth) 210 x 65 mm size, and concrete 80 x 240 mm – refer Figure 10.

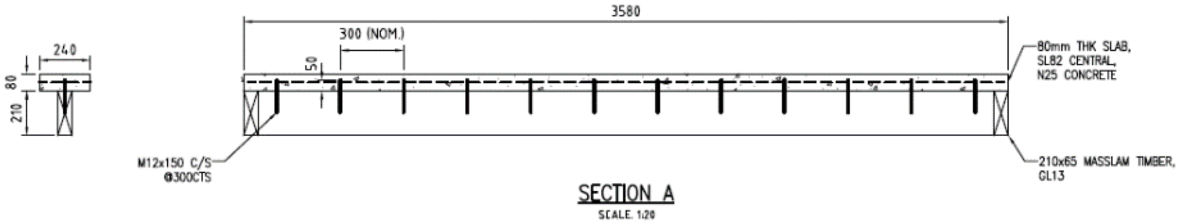


Figure 10 – Structural Beam Test Section

The specimens were tested in a 4-point loading configuration in bending (refer Figure 11) at a span of 3300 mm with deflections measured using a Linear Variable Differential Transformer (LVDT) centrally located under the beam; both load and deflections were electronically recorded. The LVDT was removed before failure to protect it from being damaged with deflections continually recorded for the cross head. All loading equipment and LVDTs were independently calibrated.

This testing was used to provide a level of confidence in the estimated design capacity of the ATC floor system but was not used to establish the system design capacity/properties.

Photos: B. Iskra [TPC Solutions (Aust) Pty Ltd]

Figure 11 – Four-point bending tests

The testing demonstrated that the modelled structural design performance of the ATC Floor System composite action was in line with expectations however further investigation of the composite action is recommended – refer section 5.1.2.

4.2. Fire Performance

The fire performance of building elements and systems used in non-domestic type buildings (e.g., apartments, offices) is governed by the National Construction Code 2022, Building Code of Australia Volume One (NCC).

The NCC Part C2 Fire resistance and stability, Table C2D2 (refer Table 3) specifies the minimum Type of fire-resisting construction required for building elements used in the construction of commercial type buildings; with the focus of this research project being Type A construction used in 3 or more storey Class 2 (apartments) and Class 3 (e.g. hotels), and 4 or more storey Class 5 (office) buildings.

Table 3 – Required Type of fire-resisting construction

Table C2D2: Type of construction required

Rise in storeys	Class of building 2, 3, 9	Class of building 5, 6, 7, 8
4 or more	A	A
3	A	B
2	B	C
1	C	C

This Table is an extract of the NCC provided by the Australian Building Codes Board © 2022. (https://ncc.abcb.gov.au/)

Specification 5, Table S5C11g (refer Table 4) of the NCC specifies the required fire-resisting construction for floors in Type A construction.

Table 4 – Floors – Fire Resistance Level (FRL)

Building element	FRL (in minutes): *Structural adequacy / Integrity / Insulation*			
	Class 2, 3 or 4 part	Class 5, 7a or 9	Class 6	Class 7b or 8
Other *loadbearing* internal walls, internal beams, trusses and columns	90/–/–	120/–/–	180/–/–	240/–/–
Floors	90/90/90	120/120/120	180/180/180	240/240/240
Roofs	90/60/30	120/60/30	180/60/30	240/90/60

This Table is a derivative of Table S5C11g of the NCC provided by the Australian Building Codes Board © 2022. (https://ncc.abcb.gov.au/)

ATC floor systems could potentially be used across the range of building classes (Class 2 to 9) defined in the NCC and therefore full-scale fire-resistance tests were undertaken to demonstrate the fire performance of the system.

The primary aim of the testing was to confirm the fire design of ATC floor systems via full-scale loadbearing fire tests and to confirm the floor system design using:

(1) the notional char rate for Victorian ash (benchmark test) as available via existing test reports or AS/NZS 1720.4:2019 *Timber Structures – Fire resistance of timber elements* for Victorian ash (benchmark test) and plantation shining gum for the design of the timber floor joist elements, and

(2) AS 3600:2018 *Concrete structures* for the fire design of the thickness of the concrete slab elements.

The fire resistance tests and resulting assessment report, has been prepared as Evidence of Suitability, in accordance with the NCC provisions (Clause A5G3), to enable the broadest field of application.

4.2.1. Full-Scale Loadbearing Fire-resistance Tests

Full-scale loadbearing fire-resistance tests were undertaken at Warringtonfire Australia, a NATA accredited fire testing laboratory, to test the fire-resistance level (FRL) achieved by the ATC floor systems; with the ATC floor systems being fully prefabricated off-site and delivered and installed at the test facility ready for testing.

Tests were undertaken using Victorian ash (benchmark test) and plantation shining gum in accordance with AS 1530.4:2014 *Methods for fire tests on building materials, components and structures: Fire-resistance tests for elements of construction* and achieved a compliant 90-minute fire resistance with additional data obtained from the remainder of the 120-minute loadbearing test to enable further assessments. The test results were then used to assess the FRL achieved (i.e., structural adequacy/integrity/insulation) by the ATC floor system for FRLs of 30/30/30, 60/60/60, 90/90/90, 120/120/120 and 180/180/180; the latter incorporating a fire-rated ceiling and achieving a *resistance to the incipient spread of fire* (RISF) of not less than 60 minutes. The assessments also considered the installation of floor penetrations (e.g., floor waste, electrical services) and provide installation details that do not reduce the fire-resisting performance of the floor system (refer Appendix 1).

To achieve the desired fire performance for a floor system to be used in multi-storey residential apartment or commercial type buildings, key design considerations were discussed with the Warringtonfire Australia assessment team during the formulation of the test program.

Specifically discussed were, the:

- loadbearing capacity of the floor system
- fire-resistance level required for the class of building
- demonstration of compliance with AS 1530.4 (report), and
- assessment to enable the installation of floor penetrations (i.e., pipework)

4.2.2. Test Specimens

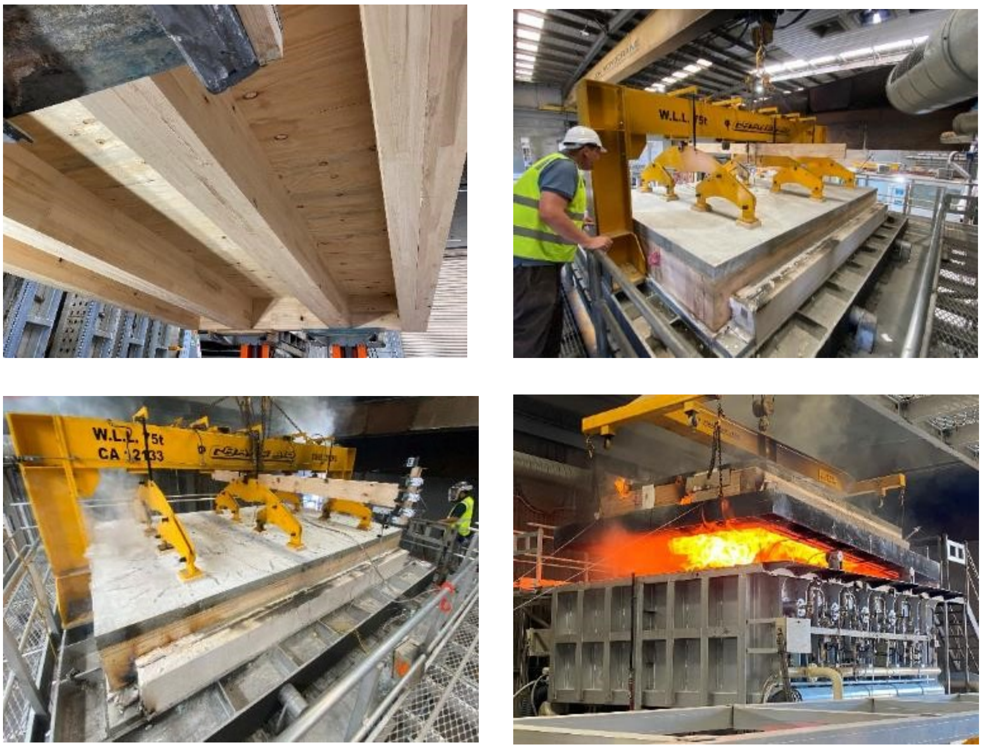
The test specimens were designed and fabricated by TGA Engineers utilising MASSLAM timber members manufactured by Australian Sustainable Hardwoods. The ATC Floor Systems were fabricated using 2 x 470 x 120 mm glued-laminated floor joists, 21 mm plywood form supporting a 100 mm thick reinforced concrete slab connected to the floor joists via M16 connectors – refer Figure 12.

Victorian ash *Plantation Shining gum*

Photos: R. Nestic [TGA Engineers]

Figure 12 – Test Specimen

The test comprised a full-scale ATC Floor System and included a 1.0 m length of floor joist cross-section timber sample in which temperature thermocouples were placed at pre-determined locations to be used to determine the char behaviour of the timber floor panel. The 1.0 m section was placed centrally within the floor panel, parallel to (and in between) the central pair of floor joists. The instrumented test was then placed on the furnace, load applied to the floor panel and the furnace activated until completion of the 120-minute test period – refer Figure 13.



Photos: B. Iskra [TPCS]

Figure 13 – Fire Testing

4.3. Acoustic Performance

The acoustic performance of building systems used in non-domestic type buildings (e.g., apartments, offices) is governed by the National Construction Code 2022, Building Code of Australia Volume One (NCC).

The NCC Part F7 Sound transmission and insulation, Clause F7D1 specifies the Deemed-to-Satisfy (DTS) provisions required for building elements used in the construction of commercial type buildings; with the focus of this research project being Class 2 (apartments), Class 3 (e.g., hotels) and Class 5 (office) buildings.

For Class 2 and 3 buildings, the NCC Clause F7D5 specifies the minimum required airborne and impact sound insulation ratings (see below).

F7D5 Sound insulation rating of floors

[2019: F5.4]

(1) A floor in a Class 2 or 3 building must have an $R_w + C_{tr}$ (airborne) not less than 50 and an $L_{n,w}$ (impact) not more than 62 if it separates—

(a) *sole-occupancy units*; or

(b) a *sole-occupancy unit* from a plant room, lift *shaft*, stairway, *public corridor*, public lobby or the like, or parts of a different classification.

This Clause is an extract of the NCC provided by the Australian Building Codes Board © 2022. (https://ncc.abcb.gov.au/)

However, the Association of Australian Acousical Consultants (AAAC) recommends that a higher tested impact performing floor system be used in apartment type buildings – refer below.

Recommended Minimum	ACCC Criteria	Improvement over NCC Criterion of $L_{nT,w} \le 62$ (dB)	AAAC Star Rating
Standard Residential apartments	$L_{nT,w} \le 55$	7	3
Minimum for luxury residential apartments	$L_{nT,w} \le 50$	12	4
Luxury residential apartments	$L_{nT,w} \le 45$	17	5
Hard floor is to have comparable high performance to a carpeted floor	$L_{nT,w} \le 40$	22	6

Extract from the WoodSolutions TDG#02 Timber-framed Construction for Multi-residential Buildings Class 2 & 3.

There are no formal acoustic insulation provisions contained in the NCC for Class 5 (office) type buildings.

4.3.1. Full-scale Acoustic Floor System Test

A full-scale ATC floor system was undertaken at the CSIRO, a NATA accredited fire testing laboratory, to test the acoustic performance (airborne and impact) achieved by the ATC floor system as the baseline test, with various floor finish and ceiling treatments applied (e.g., carpet, floating timber floor, plasterboard suspended ceiling).

The ATC floor system measured approximately 3.6 m in length x 3.0 m in width and comprised (from top of floor down): 80 mm concrete slab floor, no plywood, 210 x 65 mm plantation shining gum glued-laminated floor joists at approximately 600 mm centres. The ATC floor system was fully prefabricated off-site and delivered and installed at the test facility ready to be "prepared" for testing – refer Figure 14.

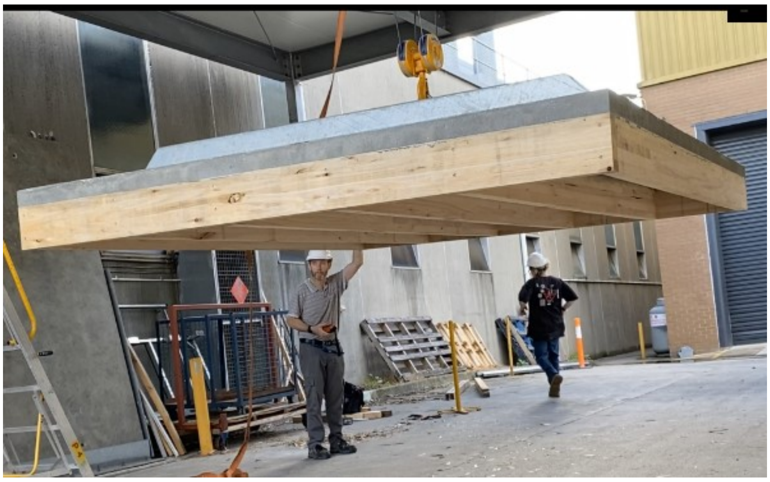
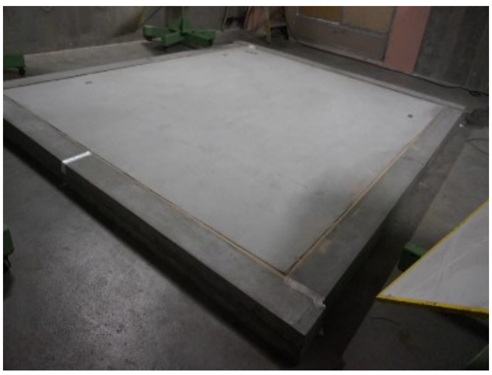


Photo: B. Iskra [TPCS]

Figure 14 – ATC Floor system

As the top surface of the ATC floor system was approximately 140 mm above the finished level of the chamber's concrete slab floor, specific detailing around the perimeter of the floor system was required for the undertaking of airborne sound insulation testing. This detailing was achieved by firstly installing two rows of 70 x 140 x 2000 mm concrete sleepers laid horizontally (flat) around the perimeter of the ATF floor system, taping the joints between and around the external edges of all the sleepers and filling the (approx.) 10 mm gap between the edge of the floor panel and edge of the concrete slab aperture opening with fine grain sand to effectively seal the gap (refer Figure 15(a)).

For the additional acoustic treatments applied to the top of the ATC Floor System, an additional row of vertical sleepers was installed, taping the joints between and around the external edges of all the sleepers (to enable easy removal of the applied), and application of an acoustic grade sealant along all joints within the floor and around the perimeter of the concrete sleepers (refer Figure 15(b)).



(a) Two rows of horizontally laid perimeter concrete sleepers
Photo: D. Truett [CSIRO]

(b) Two rows of horizontally laid perimeter concrete sleepers plus a row of vertical sleepers
Photo: B. Iskra [TPCS]

Figure 15 – Perimeter Floor Detailing

4.3.2. Acoustic Test Series

Discussions were held with Marshall Day Acoustics in formulating the various ATC Floor System layups to be tested and the data sought from the test series to enable calibration and modelling of additional floor systems. Critical to these discussions was the edge detailing of the raised acoustic treatments with numerous detailing options investigated with the final adopted approach, as described in Section 4.3.1, developed on-site in conjunction with Marshall Day Acoustics and the CSIRO to enable quick and easy installation and dismantling of the test specimens.

The floor system layups were selected to provide a range of data points that would enable confidence in the calibration of the INSUL® software package. For floor systems, a key consideration is impact noise (e.g., footfall noise) and the INSUL® software package use a model that depends on the mass, bending stiffness, the damping of the floor, as well as its impedance; the ability of the floor to resist being "excited" by the impact – the latter being determined by impact sound testing.

The proposed laboratory acoustic testing of the ATC Floor System, and the data recorded, was an innovative step taken to provide confidence in the software output. A series of tests were proposed starting with a bare concrete slab surface finish and gradually introducing a series of different floor surface treatments to prioritise solutions to allow the underside/soffit to be visually expressed; and lastly with a suspended ceiling below.

The test series was designed to account for the effects of resilient floor treatments and cavity ceiling below. By undertaking this stepwise approach to the testing, the effect of the individual floor treatments could be measured and the difference in two sets of measured impact sound pressure levels determined to give the effective improvement in impact insulation.

The installation of a suspended ceiling to the underside of the ATC Floor System also provided a direct measurement benefit. Modelling of cavity spaces formed a raised access floor in combination with a ceiling below can add a level of complication. Therefore, typical installations (raised access floor heights, ceiling cavity) were installed for the test series.

A series of airborne (4 off) and impact tests (9 off) were undertaken by the CSIRO of the proposed ATC floor system with a range of floor surface and ceiling treatments as shown and described in Table 5. Copies of test reports, that do not infringe on the intellectual property of the proprietary floor treatment systems, are provided in Appendix 2.

Airbourne Sound
Airborne sound testing was undertaken and measured in both directions through the test specimen using 3 loudspeaker positions in each acoustic chamber (above and below) giving 6 spatially independent sets of values. The noise generated in the 'source room' is very loud (in excess of 100 dB) which is measured in the 'receiver room' below the ATC Floor System – refer Figure 16. Background noise measurements are also taken in the receiving room and are used to apply corrections to account for any external sound e.g., traffic noise.

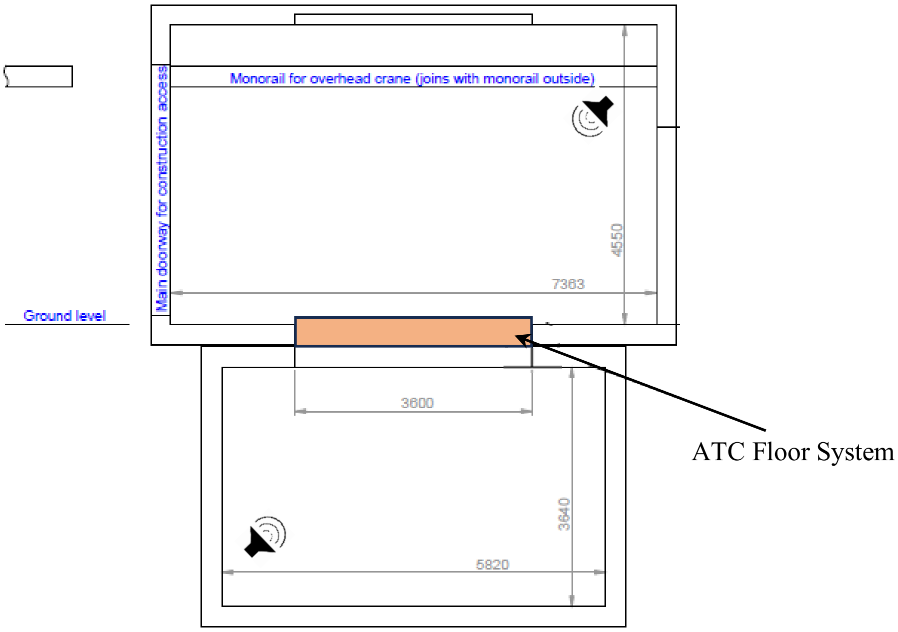


Figure 16 – Section: CSIRO Acoustic Testing Facility

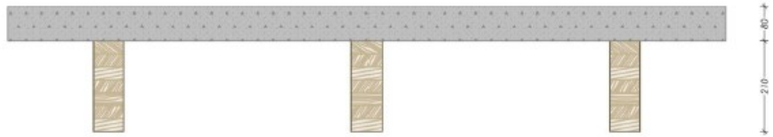
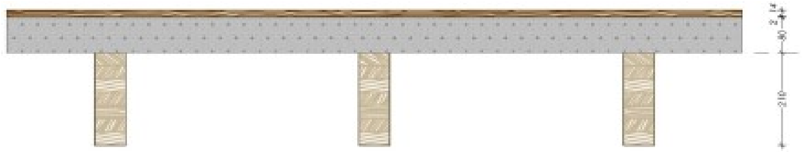
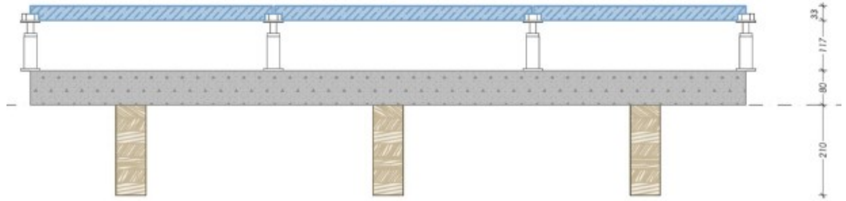
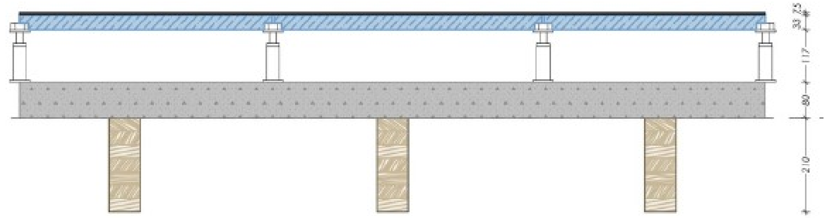
The "reverberation time", i.e., the time taken for sound to decay by 60 dB, is also measured within the receiving room which is applied to the readings to account for the characteristics and absorptiveness of the room. The difference in the two airborne noise levels, corrected for background and reverberation characteristics, is the airborne sound insulation performance of the system; the greater the airborne noise difference between the source room and the receiver room determines a higher airborne sound insulation performance.

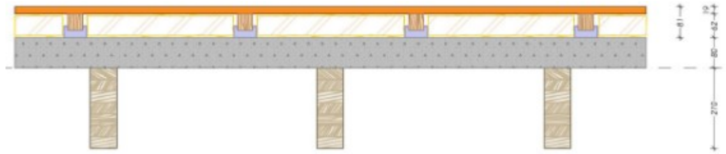
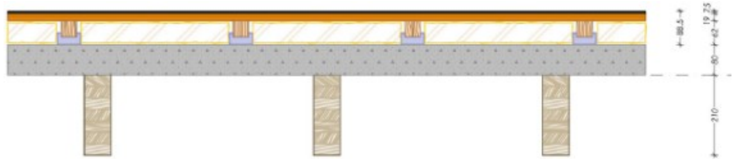
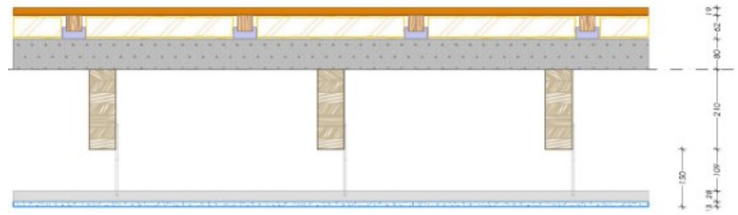
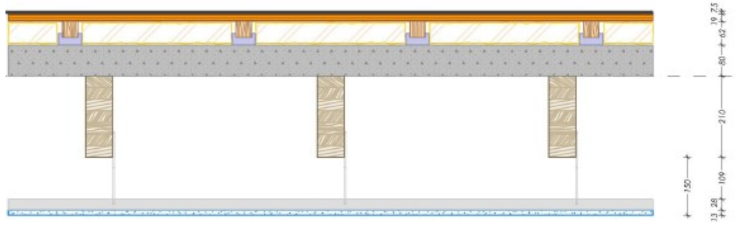
Impact Sound

Impact sound testing for the systems was undertaken using a Norsonic Nor277 tapping machine which comprises of five 'hammers' driven up and down by a cam and electric motor used to "tap" the floor surface by applying a known force on the floor structure. The tapping machine was placed diagonally in eight different locations across the test floor area. The resulting sound levels were measured in the chamber below over a whole microphone rotation (33 seconds) for each location.

Photo: B. Iskra [TPCS]

Table 5 – Acoustic Floor System Tests

ATC Floor System and Surface Treatments	Laboratory Test / Report #		Tested System Illustration
	Airborne	Impact	
1. 80 mm bare concrete slab	TL774-03-2	INR301-03-2	
2. 80 mm concrete slab *plus* 7.5 mm carpet tile (no underlay)		INR301-02-2	
3. 80 mm concrete slab *plus* 2 mm foam underlay *plus* 14 mm floating timber flooring		INR301-01-2	
4. 80 mm concrete slab *plus* ASP™ IconX Access Floor[1]	TL774-04-2	INR301-04-2	
5. 80 mm concrete slab *plus* ASP™ IconX Access Floor *plus* 7.5 mm carpet tile[1] (no underlay)		INR301-05-2	

ATC Floor System and Surface Treatments	Laboratory Test / Report #		System Illustration
	Airborne	Impact	
6. 80 mm concrete slab *plus* Batten & Cradle™ [1]	TL774-07-2	INR301-07-2	
7. 80 mm concrete slab *plus* Batten & Cradle™ *plus* 7.5 mm carpet tile[1] (no underlay)		INR301-06-2	
8. 80 mm concrete slab *plus* Batten & Cradle™ *plus* suspended 13 mm plasterboard ceiling[1]	TL774-09-2	INR301-09-2	
9. 80 mm concrete slab *plus* Batten & Cradle™ *plus* 7.5 mm carpet tile (no underlay) *plus* 13 mm suspended plasterboard ceiling[1]		INR301-08-2	

[1] *Test report(s) data not included in Appendix 2 – Commercial-in-confidence.*

4.3.3. Acoustic Test Results

The ATC floor system was installed in CSIRO's acoustic chamber (refer Figure 17) and acoustically tested using a range of floor and ceiling treatments (refer Figure 18) in accordance with:

Airborne Sound Insulation

- AS 1191-2002 (R2016): Acoustics – Method for laboratory measurement of airborne sound insulation of building elements
- AS/NZS ISO 717-1 (2004): Acoustics – Rating of sound insulation in buildings and of building elements. Part 1: Airborne sound insulation

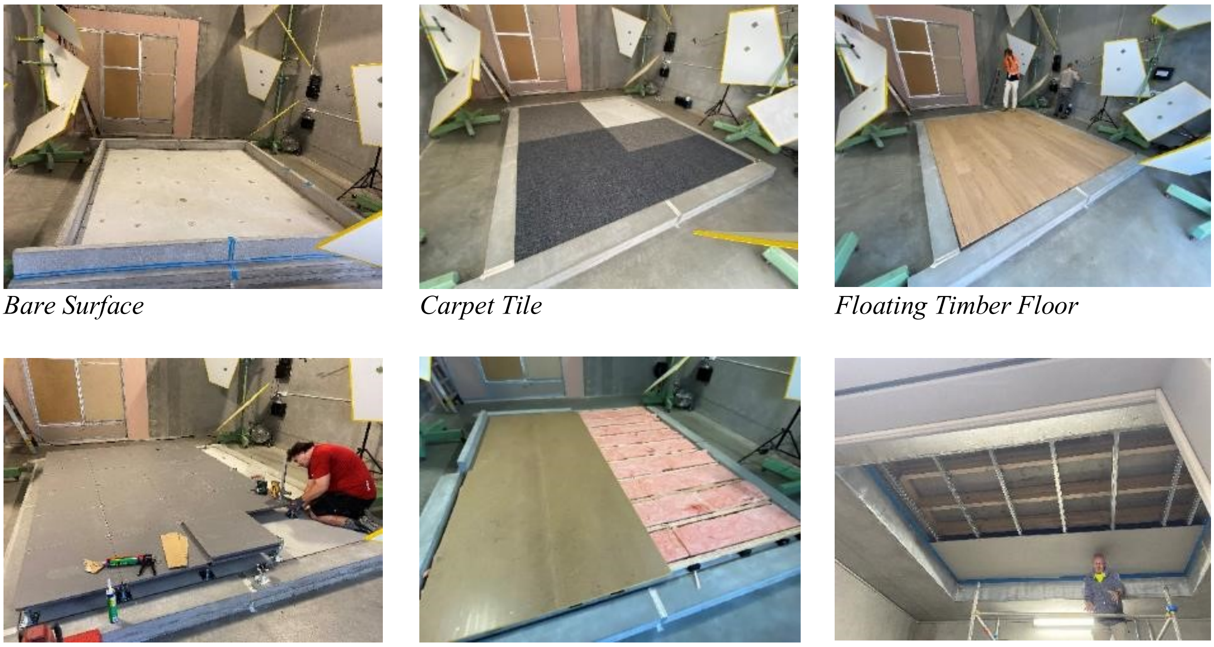
Photo: B. Iskra [TPCS]

Impact Sound Insulation

- AS ISO 140.6-2006 and ISO 10140 Part 3 (2010): Laboratory measurement of impact sound insulation of floors
- AS ISO 717.2 (2004): Acoustics – Rating of sound insulation in buildings and of building elements. Part 2: Impact sound insulation

Photos: B. Iskra [TPCS]

Figure 17 – ATC Floor System Installation (CSIRO Test Facility)



Bare Surface | *Carpet Tile* | *Floating Timber Floor*

ASP™ IconX Access Floor | *Batten & Cradle™* | *Plasterboard Ceiling*

Photos: B. Iskra [TPCS]

Figure 18 – ATC Floor System Acoustic Treatments

As the ATC Floor System is formed via a combination of buildings materials (i.e., concrete, steel reinforcement and shear connectors, glulam timber floor joists), and a range of proposed floor system treatments (floor covering system and a suspended ceiling) to be trialled, full-scale laboratory testing was considered an essential step in order to provide confidence in the real-life acoustic sound insulation performance of the systems. The results of the ATC tested floor systems were used to assist in calibration of an existing marketplace acoustic modelling software. It should be noted that this type of testing is typically not undertaken, and reliance is placed on the outputs of acoustic software packages – refer section 4.3.4.

The publicly available acoustic test reports are provided in Appendix 2.

4.3.4. Acoustic Insulation Modelling

The tested acoustic system layups, as described in "Acoustic Test Series", were incorporated into the INSUL[1] software program – a program used for predicting the sound insulation of walls, floors, roofs, ceilings, and windows – and the laboratory results were used to calibrate the software outputs of the tested systems.

Due to the innovative nature of the ATC Floor System, and the interactive nature of the various system components/elements e.g., concrete slab floor, shear keys, timber floor joists, various surface floor treatments and attached ceiling, the software predictions, in the majority of cases, were substantially more conservative than the tested equivalent. However, the modelling of the primary bare concrete ATC Floor System modelled predictions were in alignment with the tested systems.

[1] https://marshallday.com.au/innovation/software/

Therefore, the approach taken in relation to sound insulation modelling has been to use the CSIRO tested system performance as the benchmark and utilise the modelled systems where there is confidence in the software's output.

A copy of the acoustic system performance report prepared by Marshall Day Acoustics is provided in Appendix 3.

The National Construction Code 2022 (NCC) sets the minimum sound insulation/transmission performance requirements for buildings. Specifically, Part F7 Sound transmission and insulation, Clause F7O1 [2019: FO5] states that this Part "…*only applies to a Class 2 or 3 building or a Class 9c building*." i.e., apartment (Class 2) or hotel/motel (Class 3 – transient type accommodation) buildings or residential care (Class 9c) buildings respectively.

It should be noted that there are no minimum floor sound insulation provisions in the NCC for other types of buildings (e.g., Class 5 office buildings).

In respect of floor systems, NCC Clause F7D5 [2019: F5.4] specifies the required minimum sound insulation ratings, measured in decibels (dBA), which are summarised in Table 6. Note that the sound transmission insulation performance required for Class 9c buildings is less than that for Class 2 and 3 buildings. This is presumably due to the accommodation primarily being for older aged occupants who tend to be harder of hearing.

Table 6 – NCC: Minimum Sound Insulation Rating for Floors

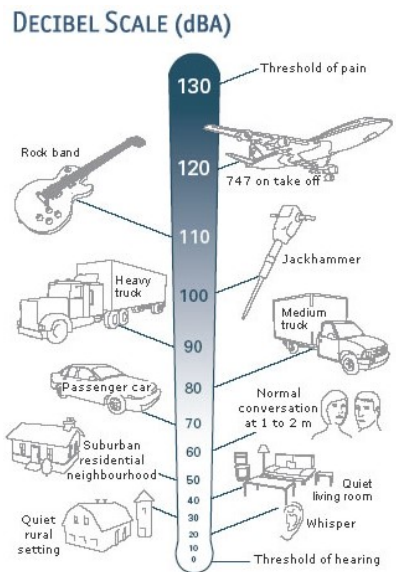
Class of Building	**Minimum Sound Insulation Rating**		
	Airborne[1]		**Impact**[3]
	R_w[2]	$R_w + C_{tr}$	$L_{n,w}$
Class 2 or 3		Not less than (≥) 50	Not more than (≤) 62
Class 9c	Not less than (≥) 45		

[1] The larger the number, the better airborne sound insulation achieved.
[2] For Class 9c buildings only (e.g., floors separating sole-occupancy units in residential care facilities).
[3] The smaller the number, the better impact sound insulation achieved.

A decibel value is based on the logarithm of the intensity of a sound. When a sound is perceived to double in loudness, this approximately a 10 dB increase in sound intensity.

Therefore, if the airborne sound insulation rating of a system is 10 dB greater than the minimum required by the NCC, or 10 dB less for the impact sound insulation rating, the noise transmission through the floor system is approximately halved i.e., achieves a much higher performance.

Floor system acoustic performance, and equally wall systems, is extremely important for multi-story residential buildings (e.g., apartments, hotels) to minimise the volume of sound heard in adjacent rooms to "… *safeguard occupants for illness or loss of amenity as a result of undue sound being transmitted*…" – NCC F7O1 Objective.

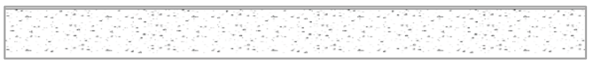
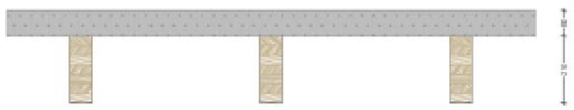
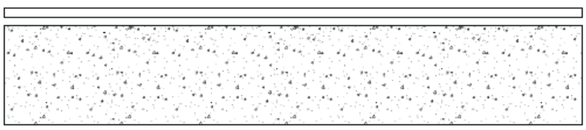
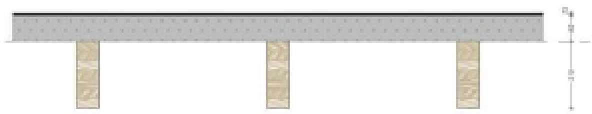


Graphic: Nick Maroulis
https://www.flickr.com/photos/maroulisnick/

The NCC provides a selection of acceptable forms of Deemed-to-Satisfy (DTS) floor system construction solutions that can be used in residential care facilities (R_w) and apartment and hotel type buildings ($R_w + C_{tr}$, $L_{n,w}$). A comparison of basic concrete slab floor systems, with similar forms of ATC Floors Systems, is shown in Table 7.

Note: NCC compliant acoustic floor systems, within the tables of this report, are highlighted in ***brown*** *for Class 9c residential care facilities and* ***green*** *for Class 2 (apartment) or 3 (e.g., hotel) buildings.*

Table 7 – Concrete Slab Floor and ATC Floor System Acoustic Comparison

Floor System/Description	**Sound Insulation Rating (dBA)**		
	R_w[1]	**$R_w + C_{tr}$**	**$L_{n,w}$**
 *(a) 100 mm thick concrete slab*[2]	45	45	N/S
 *(b) ATC Floor System with 120 mm thick concrete slab*	51 *(Modelled)*	48 *(Modelled)*	N/S
 *(c) 200 mm thick concrete slab with carpet on underlay*[3]	50	**50**	**62**
 *(d) ATC Floor System with 180 mm thick concrete slab Plus 7.5mm carpet tile (no underlay)*	56 *(Modelled)*	**50** *(Modelled)*	**49** *(Modelled)*

[1] For Class 9c buildings only (e.g., floors separating sole-occupancy units in residential care facilities).
[2] NCC Acceptable form of construction for floors – Specification 28: Figure S28C8c [2019: Spec F5.2: Table 3]
[3] NCC Acceptable form of construction for floors – Specification 28: Figure S28C8b [2019: Spec F5.2: Table 3]
N/S – Not suitable

5. Discussion

The development of an innovative structural timber composite floor system must address key design and construction related aspects to enable its market use and acceptance. Specifically, a structural floor system must achieve the desired spans, fire, and acoustic performance. This research project has investigated each of these performance measures using a plantation grown shining gum hardwood resource. The following discussion describes some of the key learnings from this test program.

5.1. Structural Testing

5.1.1. Shear Connectors

The “key” to the structural performance of the ATC Floor System is dependent on the composite action of the concrete slab floor in conjunction with the glued-laminated floor joists. This composite action is provided by the shear (key) connectors and their design capacity/performance.

As described in sections 4.1.2 and 4.1.3, an extensive range of testing was undertaken to understand the capacity of the proposed connector shear capacities and the impact of having a plywood layer, through to not having an interlayer. The reasoning behind this approach was to not only give a good understanding of the connector performance, and enable calibration of existing design methods, but give design flexibility not only to the structural engineer but to the Architect.

From an architectural perspective, this flexibility allows the Architect to either have an exposed concrete soffit/ceiling or introduce a visual timber aesthetic i.e., plywood ceiling. To achieve this, from an engineering perspective, this allows the structural engineer to use on-site concrete forms that can be stripped away from the ceiling once the concrete has set or prefabricate the ATC Floor System as cassettes and deliver them to site for immediate installation.

The plantation shining gum shear connector testing was undertaken in a comparative way due to the vast amount of design information available for Victorian ash; which was therefore used as a benchmark for the test program.

An analysis of the test program found that:

Type A – M16 coach screw embedded 100mm into the timber beam section with 50 mm projecting into the concrete slab and inserted at 90 degrees to the timber interface. All tests provided a high ultimate capacity with a moderate ductility up to ultimate load, then a rapid drop in strength either due to timber splitting or fastener yielding. The characteristic strength and stiffness compare well with AS 1720.1.

Type B – M10 full threaded screws embedded at 45 degrees to the interface with a 50 mm projection into the concrete slab. Stiffness was comparable to the M16 coach screws, however joint stiffness was high at the 2.5mm slip. Once the maximum load was achieved the inclined screws exhibited an excellent degree of ductility.

Type C – 2/M10 vertical washer head screws in conjunction with a 50 x 20 mm polyurethane glued in timber block was limited to the shear strength of the block in the longitudinal grain direction. The maximum load was relatively low for the complexity of the joint. This type of connector was brittle in nature with low slip displacement.

Type D – M20 bolt epoxy glued into the timber beam at 90 degrees to the timber interface. As expected, the joint stiffness was high compared to the other connector types. However, it highlighted the need to design check the fastener capacity in the concrete slab. All specimens failed by concrete plug out or splitting. Therefore, it is believed the true ultimate capacity of the joint was not achieved and further investigation is required to determine the concrete connector capacity, and the appropriate concrete thickness required.

As can be seen in Table 8, the characteristic values based of the M16 coach screw fastener (Type A) at 90 degrees to interface compares well to the predicted values. AS 1720.1 does not provide a design methodology for inclined screws and further research is required.

Table 8 – Characteristic Shear Connector Type Capacity

CONNECTION TYPE	PLYWOOD	STRENGTH		STIFFNESS			
		Qk	AS 1720	Ks 0.5mm	ks AS1720	ks 2.5mm	ks AS1720
A	NO PLYWOOD	15.71	12.89	16021	15595	8626	4799
	15MM PLYWOOD	10.15	-	12394	-	7242	-
	25MM PLYWOOD	11.09	-	9741	-	5543	-
B	NO PLYWOOD	14.71	-	14248	-	12116	-
	15MM PLYWOOD	12.23	-	6861	-	8213	-
	25MM PLYWOOD	12.36	-	6631	-	6635	-
C	NO PLYWOOD	11.67		11567	-	-	-
	15MM PLYWOOD	9.27		13853	-	-	-
	25MM PLYWOOD	9.76		12863	-	-	-
D	NO PLYWOOD	15.66	28.40	17878	-	14128	8957
	15MM PLYWOOD	16.56	-	26153	-	14396	-
	25MM PLYWOOD	14.66	-	9398	-	9964	-

The testing demonstrated that the modelled structural design performance of the ATC Floor System composite action was in line with expectations and provided a level of confidence.

5.1.2. Full-Scale Beam Test

The full-scale "T-section" beam specimens were obtained from the full-scale plantation shining gum panel fabricated for the acoustic test. As the acoustic test was to target minimum performance, the concrete slab floor thickness was only 80 mm and did not include a plywood interlayer.

This however, from a structural testing perspective, was positive on two fronts. Firstly, it made handling of the test specimens within the laboratory easier as the samples were relatively lighter and able to be physically manoeuvred within the test rig once put in place with the assistance of a forklift. Secondly, the measurements taken during testing were the interaction between concrete floor slab and the timber glulam beams, via the shear connectors. This removed a potential variable of the plywood interlayer.

Different specimen test setups were considered to enable efficient placement, loading and removal of the specimen post-test. Following discussions with the test facility, it was decided to test the specimens in an upright "T" section position with lateral support provided at both ends of the test specimen – refer section 4.1.3. The test setup performed extremely effectively and enabled testing to be undertaken quickly and efficiently.

As can be seen in Table 9, the measured system stiffness exceeds the calculated stiffness by at least 41%; depending on which methodology is adopted. The European methodology adopts the stiffness between the 10% and 40% of the maximum load. All specimens ultimately failed in the timber section due to combined bending and tension on the bottom edge. The load versus displacement curves exhibited a non-linear behaviour, due to slip and non-linear behaviour of timber.

Table 9 – Tested System Strength and Stiffness

test	Ultimate load (kN)	Ultimate moment (kNm)	Eixx (initial)	Eixx 10-40% (serviceability)	Eixx 60% (serviceability)
1	52.402	28.82	2.13E+12	2.94E+12	2.57E+12
2	67.334	37.03	2.15E+12	2.22E+12	1.78E+12
3	50.492	27.77	1.86E+12	2.06E+12	1.73E+12
4	80.674	44.37	2.07E+12	1.96E+12	1.51E+12
mean	62.726	34.50	2.05E+12	2.29E+12	1.90E+12
Euromethod			1.35E+12	1.35E+12	1.35E+12
			153%	170%	141%

Due to the high beam stiffness compared to the calculated value, further investigation is required to fully understand the behaviour; as:

- the gamma method may be conservative,
- there maybe load sharing due to joint slip, and
- as the timber section is predominantly in tension, the stiffness (Modulus of Elasticity) maybe underestimated.

However, the testing provided a high level of confidence that the current methodology for design is appropriate and further research could be undertaken to provide a more accurate model and a refined economical system.

5.2. Acoustic Test Series

The full-scale plantation shining gum acoustic test panel, as described in section 4.3.1, was precisely prefabricated and included lifting bolts to which a metal "H-frame" was attached to enable the lifting of the panel off a flatbed truck. The panel was lifted off the truck and then guided through twin open doors into the upper acoustic chamber, via an overhead monorail and hoist setup, and positioned in place – refer Figure 19. Tight panel dimensioning was required to finish approximately 10 mm short on all four edges of the panel i.e., a 10 mm perimeter gap. This gap and the lifting bolt hole positions were then filled with fine sand to fill the edge gaps around the panel, and bolt holes, and essentially "seal" the upper chamber from the lower chamber.

Installation of Acoustic Test Panel *Lifting bolts*

Photos: B. Iskra [TPCS]

Figure 19 – Acoustic Panel Positioning

The sealing of gaps was essential to prevent the transfer of noise through to the lower chamber and very effort was made to seal the gaps – refer Figure 20. This was critically important for the testing of elevated acoustic treatments placed onto the ATC Floor System e.g., ASP® Access Floors.

Sleepers with Acoustic Sealant Treatment *Ceiling with Acoustic Sealant Treatment*

Photos: B. Iskra [TPCS]

Figure 20 – Perimeter Sealing

Once the ATC Floor System was in place and sealed, changes to the top surface were relatively quickly made which enabled several tests to be completed on the same day; the acoustic system test arrangement was suggested by CSIRO to enable quick and efficient testing.

The ATC Floor System panel was fabricated with an 80 mm concrete floor slab with no plywood interlayer between the concrete and the glulam timber floor joists. This was done to represent a lower bound acoustic system performance. The various tests were used to enable calibration of the INSUL® software package which was then used to generate variations in the system layup. Marshall Day Acoustics were provided copies of the CSIRO system test reports, as detailed in Table 5, and used to undertake calibration of the INSUL® software package which proved challenging.

The results of the acoustic modelling demonstrated that the ATC Floor System can be competitive against the traditional forms of floor construction i.e., concrete as shown in Table 7. The ATC Floor System with a thin concrete slab floor (e.g., 80 mm) with a form of flooring overlay, performed reasonably well in relation to impact sound insulation however not well in relation to airborne sound insulation. This demonstrates that, for the ATC Floor System, the system will generally be governed by airborne sound transfer requiring a thicker concrete floor slab. Impact sound insulation can be addressed using various floor treatments as shown in Table 10.

The floor treatments for the systems shown in Table 10 may be further modified/varied and modelled using the INSUL® software package. The addition of carpet underlay, thicker floating timber flooring foam underlay, rubber pads installed under the pedestal supports of the ASP™ IconX Access Floor through to installing ceiling insulation with the suspended ceiling cavity will all further enhance the acoustic insulation performance of the ATC Floor System.

When the ATC Floor System is fabricated on-site, a plywood interlayer (form) can be used onto which the steel reinforcing mesh is placed, and the concrete poured to form the floor slab. To cater for this, an investigation was undertaken in relation to the use of the plywood interlayer on the system's acoustic performance; this was again modelled using the INSUL® software package,

A selection of ATC Floor Systems were modelled using a 21 mm thick plywood interlayer for a range of timber densities i.e., 500 to 700 kg/m^3. The modelled runs demonstrated that at worst there was no change in acoustic performance compared to the CSIRO tested systems and at best there was typically a 1-2 dBA improvement in acoustic performance for thinner concrete floor slabs i.e., 80 mm and 120 mm – refer to the modelled systems in Table 12. As the concrete floor slab increases in thickness, the beneficial effect of the plywood is diminished due to the comparative difference in densities i.e., concrete/steel 2400 kg/m^3 to plywood 500 kg/m^3.

The investigation confirmed that the use of a plywood interlayer did not diminish the acoustic performance of the ATC Floor System.

Table 10 – Tested/Modelled Minimum ATC Floor System Performance

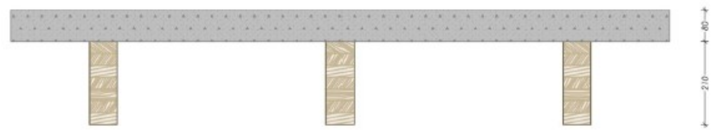
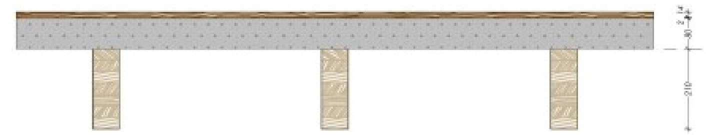
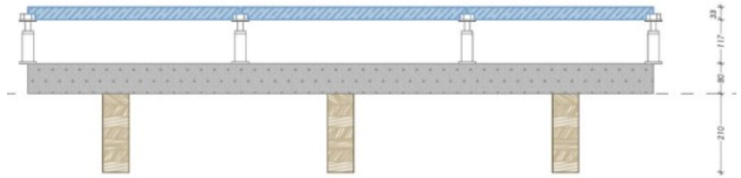
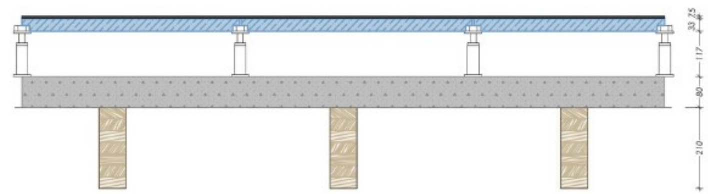
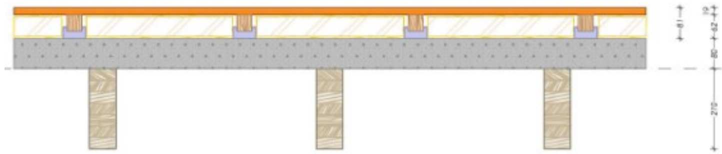
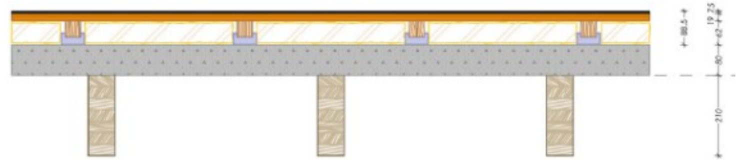
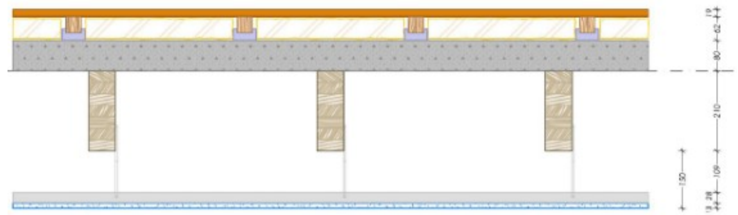
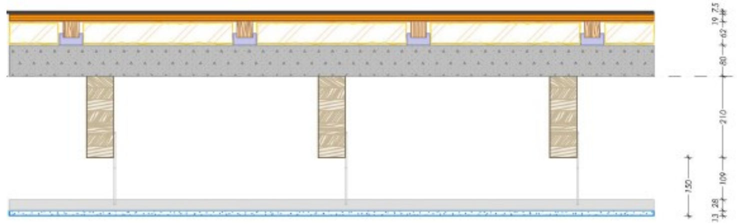
ATC Floor System and Surface Treatments	System Acoustic Performance			Tested System Illustration
	Airborne		Impact	
	R_w[1]	$R_w + C_{tr}$	$L_{n,w}$	
1. (a) 80 mm bare concrete slab	**48**	44	87	
(b) 180 mm bare concrete slab	**56**	50	75	
2. (a) 80 mm concrete slab *plus* 7.5 mm carpet tile (no underlay)	**48**	44	56	
(b) 180 mm concrete slab *plus* 7.5 mm carpet tile (no underlay)	**56**	**50**	**49**	
3. (a) 80 mm concrete slab *plus* 2 mm foam underlay *plus* 14 mm floating timber flooring	**50**	47	63	
(b) 120 mm concrete slab *plus* 2 mm foam underlay *plus* 14 mm floating timber flooring	**54**	**50**	**59**	
4. (a) 80 mm concrete slab plus ASP™ IconX Access Floor	**50**	43	62	
(b) 180 mm concrete slab plus ASP™ IconX Access Floor	**56**	**50**	**56**	
5. (a) 80 mm concrete slab *plus* ASP™ IconX Access Floor *plus* 7.5 mm carpet tile (no underlay)	**50**	43	54	
(b) 180 mm concrete slab *plus* ASP™ IconX Access Floor *plus* 7.5 mm carpet tile (no underlay)	**56**	**50**	**52**	

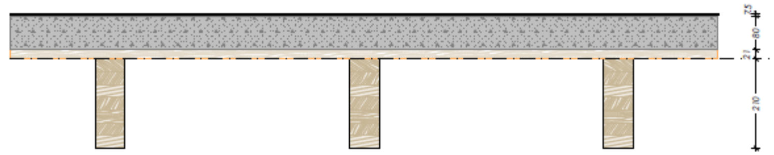
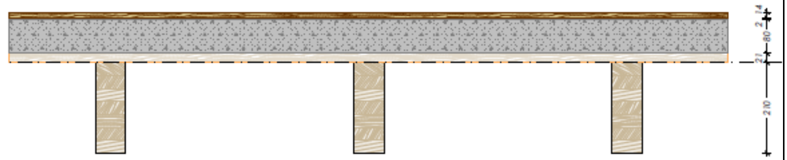
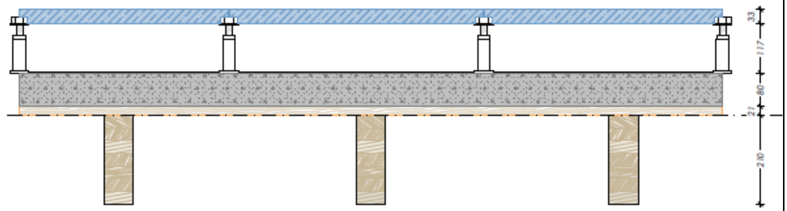
Table 11 – Tested/Modelled Minimum ATC Floor System Performance *Cont.*

ATC Floor System and Surface Treatments	System Acoustic Performance			Tested System Illustration
	Airborne		Impact	
	R_w[1]	$R_w + C_{tr}$	$L_{n,w}$	
6. (a) 80 mm concrete slab *plus* Batten & Cradle™	**57**	**52**	**51**	
(b) 120 mm concrete slab *plus* Batten & Cradle™	**60**	**54**	**48**	
7. 80 mm concrete slab *plus* Batten & Cradle™ *plus* 7.5 mm carpet tile (no underlay)	**57**	**52**	**45**	
8. 80 mm concrete slab *plus* Batten & Cradle™ *plus* suspended 13 mm plasterboard ceiling	**67**	**58**	**45**	
9. 80 mm concrete slab *plus* Batten & Cradle™ *plus* 7.5 mm carpet tile (no underlay) *plus* 13 mm suspended plasterboard ceiling	**67**	**58**	**40**	

[1] For Class 9c buildings only (e.g., floors separating sole-occupancy units in residential care facilities).

Table 12 – Modelled Minimum ATC Floor System Performance: 21 mm Plywood Interlayer

(Note: The first number in the ATC Floor System numbering below correlates to the system as shown in Table 10 without the plywood interlayer (PI))

ATC Floor System, 21 mm Plywood Interlayer, and Surface Treatments			System Acoustic Performance			Modelled System Illustration
			Airborne		Impact	
			R_w[1]	$R_w + C_{tr}$	$L_{n,w}$	
2-21PI	(a)	80 mm concrete slab *on* 21 mm plywood interlayer *plus* 7.5 mm carpet tile (no underlay)	**49**	44	54	
	(b)	180 mm concrete slab *on* 21 mm plywood interlayer plus 7.5 mm carpet tile (no underlay)	**57**	**50**	**49**	
3-21PI	(a)	80 mm concrete slab *on* 21 mm plywood interlayer *plus* 2 mm foam underlay *plus* 14 mm floating timber flooring	**51**	47	62	
	(b)	120 mm concrete slab *on* 21 mm plywood interlayer *plus* 2 mm foam underlay *plus* 14 mm floating timber flooring	**55**	**52**	**59**	
4-21PI	(a)	80 mm concrete slab *on* 21 mm plywood interlayer *plus* ASP™ IconX Access Floor	**50**	43	61	
	(b)	180 mm concrete slab *on* 21 mm plywood interlayer *plus* ASP™ IconX Access Floor	**56**	**50**	**56**	

[1] For Class 9c buildings only (e.g., floors separating sole-occupancy units in residential care facilities).

5.3. Fire Test

The full-scale fire test of the plantation shining gum ATC Floor System posed a few difficulties when trying to obtain the most technical data from the fire test as possible and achieving a compliant test. The difficulty in undertaking such fire testing is the number of variables that can impact on the fire performance such as: glueline integrity, timber char behaviour after extended periods of extreme furnace temperatures (e.g., at 120 minutes furnace at 1050°C), the interaction between, and effect of, the system components in fire (concrete, plywood, glulam, metal shear keys) and maintaining the furnace temperatures in accordance with the standard time-temperature heating regime as described in AS 1530.4:2014.

Conscious decisions were made in relation to the fabrication of the ATC Floor System test specimen including glue-laminating 2 x 370 mm x 120 mm to form 370 mm x 240 mm floor joists to enable such construction, thicker plywood interlayer (21 mm) to investigate the burning behaviour at the floor joist, plywood and concrete floor slab intersection, though to the use of a 100 mm thick concrete floor slab to determine whether the use of the plywood interlayer would enable the thermal insulation criteria to be met.

The tests demonstrated that the designed ATC Floor System panel achieved the desired fire-resistance level for the design floor load. This enabled Warringtonfire Australia to prepare an assessment report (refer Appendix 1) for the ATC Floor System for various FRLs based on concrete floor slab thickness, the use of different thickness plywood (or not) and the effective char depth of the timber beams. A summary extract of the report findings is provided in Table 13.

Table 13 – Shining Gum Fire Assessment

Construction	Plywood thickness (mm)	Minimum concrete thickness (mm)	Effective char depths of beams (mm)	Encapsulation	Requirements	FRL
ATC floor system with shining gum glued laminated timber (GLT) beams	ATC floor systems with plywood thickness < 21 mm or no plywood	60	27.2	Exposed timber beams	Plantation shining gum GLT beams must be designed by a professional structural engineer to meet the structural adequacy criteria considering the effective char depths provided in this assessment report.	30/30/30
		80	47.4			60/60/60
		100	67.7			90/90/90
		120	87.9			120/120/120
		120	77.7	2 × 16 mm fire-rated plasterboard ceiling		180/180/180
		120	47.4	3 × 16 mm fire-rated plasterboard ceiling		180/180/180
	ATC floor systems with plywood thickness ≥ 21 mm	60	27.2	Exposed timber beams		30/30/30
		80	47.4			60/60/60
		90	67.7			90/90/90
		110	87.9			120/120/120
		120	77.7	2 × 16 mm fire-rated plasterboard ceiling		180/180/180
		120	47.4	3 × 16 mm fire-rated plasterboard ceiling		180/180/180

The test specimen was loaded to support a uniformly distributed floor live (imposed) load of 7.0 kPa for the first 90 minutes then reduced to 5.5 kPa for the remaining 30 minutes of the test. These loads are substantial given that apartment buildings are typically designed for an FRL 90/90/90 and support imposed loads of 2.0 kPa; and office buildings are design for an FRL 120/120/120 and support imposed loads of 3.0 kPa with balconies supporting imposed loads not less than 4.0 kPa. Therefore, the test has demonstrated a wide application of the result to all types of buildings.

An interesting finding was that the introduction of the 21 mm plywood interlayer provided a level of insulation protection for the concrete floor slab and a 10 mm reduction in concrete slab thickness for both the FRL 90/90/90 and FRL 120/120/120 floor systems. Over multibuilding levels, this would equate to an approximate 10% reduction in concrete for the floor slab reducing material and installation costs, overall structure weight and installation time.

Although not formally tested within this project, an assessment of the system fire performance was also undertaken to enable the floor system to be used in FRL 180/180/180 applications. This assessment was based on a previous fire testing of fire-grade plasterboard systems which demonstrated the protection provided by 2- and 3-layer fire-grade plasterboard systems.

As with any system used in a commercial building, there will be a need to enable services to pass through fire-rated systems – refer Figure 21. The majority of services have been tested in conjunction with a concrete slab floor. This made penetrating the ATC Floor System relatively simple provided the plywood was "cut short" of the required/tested fire-protection system (e.g., fire collar).

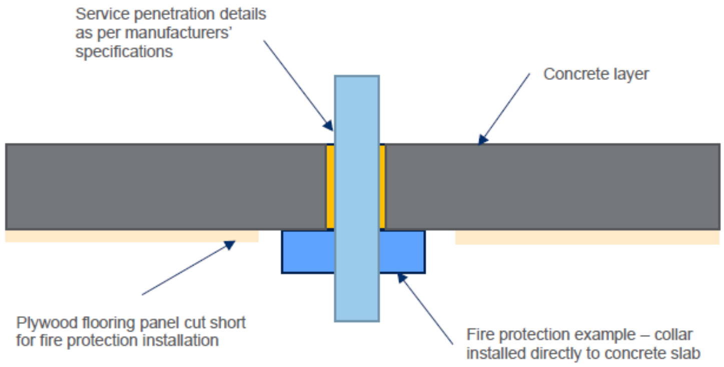


Figure 21 – Service penetrations through the ATC Floor System

The ATC Floor System has been tested to provide confidence in the fire-performance of the system. Given the floor system variables (e.g., glulam beams, slab thickness, plywood interlayer), the tests undertaken performed extremely well and achieved the desired fire-resistance performance for use in apartment and office type buildings with the potential for use in other types of buildings if desired.

6. ATC Floor System Design – Case Studies

Following completion of the test program, TGA Engineers updated their engineering design spreadsheet, as described in section 4.1.1, to incorporate the research findings. Design case studies have been prepared detailing the design of an ATC Floor System for a non-fire case as well as a fire design case. These case studies are provided in Appendix 4.

7. Conclusions

The development of innovative timber building systems/elements is complex due to the range of system functionality that must address. This research project has successfully addressed the required National Construction Code 2022 (NCC) requirements in relation to structural, fire and acoustic performance to enable the design of an Advance Timber Composite (ATC) plantation shining gum floor system to be used in the commercial market.

This report has described the research activities undertaken in investigating, developing, testing and validating design methodologies for an innovative floor system, using the plantation shining gum (*Eucalyptus nitens*) resource from the Gippsland region. The advanced timber composite (ATC) Floor System has designed to deliver a large span, acoustically quiet, and fire-rated floor system in compliance with the National Construction Code 2022 (NCC) building provisions and market demands.

The NCC sets the minimum performance requirements for new buildings in relation to health (including acoustic performance) and safety (including structural and fire performance), as well as other design considerations. This project undertook specific testing to investigate the key NCC provisions that directly relate to floor systems; these being–

- Acoustic performance – Airborne and impact sound
- Structural performance, and
- Fire performance – up to 120 minutes

This project has demonstrated that plantation shining gum can be designed and fabricated to achieve the required:

- structural design capacity utilising AS 1720.1 and Eurocode design procedures,
- NCC fire-resistance level (FRL) performance requirements for commercial buildings using fully exposed timber elements up to an FRL of 120/120/120 and, in combination with a dropped fire-grade ceiling below, an FRL of 180/180/180, and
- NCC acoustic insulation performance utilising various floor surface and ceiling treatment combinations.

8. Recommendations

This research project has demonstrated the ability to successfully undertake a range of tests in support of an innovative floor system. During this research, it was evident that further research could be undertaken to refine the floor system performance and enhance technical undertaking performance.

Opportunities for further research include:

- Long-term deflection behaviour of the plantation shining gum composite floor system to provide confidence and reliability of the plantation structural design properties.
- Dynamic performance of large span plantation shining gum composite floor systems.
- Char-rate behaviour of mass timber elements under different heating regimes (e.g., hydrocarbon fire) to increase understanding of the fire and sacrificial char behaviour.
- Acoustic (airborne, impact) behaviour of composite floor system with different component configurations e.g., thicker concrete slab floor, different floor surface finishes and ceiling treatments.
- Innovative types of shear connectors that may enable improved constructability and spanning capability.
- Design methodology for inclined screws.
- The use of fire-retardant treatments to enhance the fire performance of the plywood interlayer and plantation shining gum floor joists.
- The composite behaviour of these systems, through the targeted measuring and testing of the individual components i.e., concrete, plywood, and timber beam components, to obtain a more accurate model that may provide a more economical system.

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- Robert Nestic (TGA Engineers)

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- Peter Huston, Pete Snowden (Batten & Cradle™ Flooring Systems) – Supplier and Installers
- Julian O'Dowd (GH Commercial) – Supplier of carpet tiles

11. Researcher's Disclaimer

This research project report has been prepared by TPC Solutions (Aust) Pty Ltd [TPCS] for NIFPI/FWPA on behalf of the collaborating partners. While reasonable efforts have been made to ensure that the contents of this report are based on the best available information and data, TPC Solutions (Aust) Pty Ltd shall not be liable for any loss or damage that may be occasioned directly or indirectly through the use of or reliance on the information contained within the report. In particular, no representation, or warranty either express or implied, is given as to the likely performance, in-situ or otherwise, of a ATC floor system designed on the basis of the findings in this report.

Appendix 1 – Full-scale Loadbearing Fire Test Assessment Report

Regulatory information report

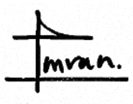
Assessment of Advanced Timber Composite (ATC) floor systems

Sponsor: Australian Sustainable Hardwoods (ASH)

Report number: FAS220092 Revision: RIR1.4

Issued date: 20 October 2023 Expiry date: 30 June 2028

Quality management

Version	Date	Information about the report		
RIR1.0	-	Reason for issue	Not issued	
RIR1.1	Issue: 26 Jun 2023	Reason for issue	Report issued in conjunction with fire assessment report FAS220092 R1.1.	
			Prepared by	**Reviewed by**
		Name	Edward Kwok	Imran Ahamed
RIR1.2	Issue: 24 Aug 2023	Reason for issue	Report issued in conjunction with fire assessment report FAS220092 R1.2.	
			Prepared by	**Reviewed by**
		Name	Edward Kwok	Imran Ahamed
RIR1.3	Issue: 16 Oct 2023	Reason for issue	Report issued in conjunction with fire assessment report FAS220092 R1.3.	
			Prepared by	**Reviewed by**
		Name	Edward Kwok	Imran Ahamed
RIR1.4	Issue: 20 Oct 2023	Reason for issue	Report issued in conjunction with fire assessment report FAS220092 R1.4.	
			Prepared by	**Reviewed by**
	Expiry: 30 Jun 2028	**Name**	Edward Kwok	Imran Ahamed
		Signature		

Executive summary

This report contains the minimum information required for regulatory compliance and refers to the referenced assessment report FAS220092 R1.4.

The analysis conducted in the referenced assessment report documents the findings of the assessment undertaken to determine the expected fire resistance level (FRL) of the Advanced Timber Composite (ATC) floor systems in accordance with AS 1530.4:2014.

The analyses in sections 5 and 6 of the referenced assessment report found that the proposed systems, together with the described variations, are expected to achieve the FRL as shown in Table 1 – in accordance with AS 1530.4:2014.

The variations and outcome of this assessment are subject to the limitations and requirements described in sections 2, 3 and 6 of this report. The results of this report are valid until 30 June 2028.

Table 1 Assessment outcome

Construction	Plywood thickness (mm)	Minimum concrete thickness (mm)	Effective char depths of beams (mm)	Encapsulation	Requirements	FRL
ATC floor system with shining gum glued laminated timber (GLT) beams	ATC floor systems with plywood thickness < 21 mm or no plywood	60	27.2	Exposed timber beams	Plantation shining gum GLT beams must be designed by a professional structural engineer to meet the structural adequacy criteria considering the effective char depths provided in this assessment report.	30/30/30
		80	47.4			60/60/60
		100	67.7			90/90/90
		120	87.9			120/120/120
		120	77.7	2 × 16 mm fire-rated plasterboard ceiling		180/180/180
		120	47.4	3 × 16 mm fire-rated plasterboard ceiling		180/180/180
	ATC floor systems with plywood thickness ≥ 21 mm	60	27.2	Exposed timber beams		30/30/30
		80	47.4			60/60/60
		90	67.7			90/90/90
		110	87.9			120/120/120
		120	77.7	2 × 16 mm fire-rated plasterboard ceiling		180/180/180
		120	47.4	3 × 16 mm fire-rated plasterboard ceiling		180/180/180

Construction	Plywood thickness (mm)	Minimum concrete thickness (mm)	Effective char depths of beams (mm)	Encapsulation	Requirements	FRL
ATC floor system with Victorian ash GLT beam (MASSLAM 45)	ATC floor systems with plywood thickness < 21 mm or no plywood	60	24.7	Exposed timber beams	Victorian ash GLT beams must be designed by a professional structural engineer to meet the structural adequacy criteria considering the effective char depths.	30/30/30
		80	42.4			60/60/60
		100	60.1			90/90/90
		120	77.8			120/120/120
		120	70.1	2 × 16 mm fire-rated plasterboard ceiling		180/180/180
		120	42.4	3 × 16 mm fire-rated plasterboard ceiling		180/180/180
	ATC floor systems with plywood thickness ≥ 21 mm	60	24.7	Exposed timber beams		30/30/30
		80	42.4			60/60/60
		90	60.1			90/90/90
		110	77.8			120/120/120
		120	70.1	2 × 16 mm fire-rated plasterboard ceiling		180/180/180
		120	42.4	3 × 16 mm fire-rated plasterboard ceiling		180/180/180

Notes:

- Concrete slab and shear connectors must be designed by a professional structural engineer.
- The effective char depths of beams shown in this table is for the sides and the bottom face of the timber beams.
- The glued laminated timber beams can be spaced at maximum 1200 mm centres.
- For ATC floor system with a fire-rated plasterboard ceiling:
  - The timber beams must be spaced at maximum 600 mm centres, otherwise;
  - The fire-rated plasterboards must be installed onto a steel supporting frame with a grid of 600 mm × 600 mm.
- Service penetrations can pass through the ATC floor system as long as the fire stopping elements are fixed or installed directly to the concrete surface. If there is a plywood layer present, it must be cut short to accommodate the installation of these fire stopping products. The referenced assessment report does not assess the fire performance of such penetrations. The fire resistance performance of such service penetrations must be established using the results from the relevant passive fire protection supplier for tested or assessed services penetrating a concrete slab of equivalent thickness by an Accredited Testing Authority (ATL) in accordance with AS 1530.4:2014.

Contents

1. Introduction

This report contains the minimum information sufficient for regulatory compliance and refers to the assessment report FAS220092 R1.4.

The analysis conducted in the referenced assessment report documents the findings of the assessment undertaken to determine the expected fire resistance level (FRL) of the Advanced Timber Composite (ATC) floor systems in accordance with AS 1530.4:2014[1].

The referenced assessment report may be used as evidence of suitability in accordance with the requirements of the relevant National Construction Code (NCC) to support the use of the material, product, form of construction or design as given within the scope of the referenced assessment report. It also references test evidence for meeting deemed to satisfy (DTS) provisions of the NCC that apply to the assessed systems.

The referenced assessment was carried out at the request of Australian Sustainable Hardwoods (ASH).

The sponsor details are included in Table 2.

Table 2 Sponsor details

Sponsor	Address
Australian Sustainable Hardwoods (ASH)	4 Weir Road Heyfield VIC 3858 Australia

2. Framework for the assessment

2.1 Assessment approach

An assessment is a professional opinion about the expected performance of a component or element of structure subjected to a fire test.

No specific framework, methodology, standard or guidance documents exists in Australia for undertaking these assessments. We have therefore followed the 'Guide to undertaking technical assessments of the fire performance of construction products based on fire test evidence' prepared by the Passive Fire Protection Forum (PFPF) in the UK in 2021[2].

This guide provides a framework for undertaking assessments in the absence of specific fire test results. Some areas where assessments may be offered are:

- Where a modification is made to a construction which has already been tested
- The interpolation or extrapolation of results of a series of fire resistance tests, or utilisation of a series of fire test results to evaluate a range of variables in a construction design or a product
- Where, for various reasons – eg size or configuration – it is not possible to subject a construction or a product to a fire test.

Assessments can vary from relatively simple judgements on small changes to a product or construction through to detailed and often complex engineering assessments of large or sophisticated constructions.

The referenced assessment uses established empirical methods and our experience of fire testing similar products to extend the scope of application by determining the limits for the design and performance based on the tested constructions and performances obtained. The assessment is an

[1] Standards Australia, 2014, Methods for fire tests on building materials, components and structures – Part 4: Fire-resistance tests for elements of construction, AS 1530.4:2014, Standards Australia, NSW.

[2] Passive Fire Protection Forum (PFPF), 2021, Guide to undertaking technical assessments of the fire performance of construction products based on fire test evidence, Passive Fire Protection Forum (PFPF), UK.

evaluation of the potential fire resistance performance of the elements in accordance with AS 1530.4:2014.

The referenced assessment has been written in accordance with the general principles outlined in EN 15725:2010[3] for extended application reports on the fire performance of construction products and building elements.

The referenced assessment has been written using appropriate test evidence generated at accredited laboratories to the relevant test standard. The supporting test evidence has been deemed appropriate to support the manufacturer's stated design.

2.2 Compliance with the National Construction Code

The referenced assessment report has been prepared to meet the evidence of suitability requirements of the NCC 2022[4] under A5G3 (1) (d). It references test evidence for meeting deemed to satisfy (DTS) provisions of the NCC under A5G5 for fire resistance level that apply to the assessed systems based on Specifications 1 and 2 for fire resistance for building elements.

The referenced assessment report may also be used to demonstrate compliance with the requirements for evidence of suitability under the relevant sections of previous versions of the NCC.

2.3 Declaration

The 'Guide to undertaking technical assessments of the fire performance of construction products based on fire test evidence' prepared by the PFPF in the UK requires a declaration from the client. By accepting our fee proposal on 6 April 2023, Australian Sustainable Hardwoods (ASH) confirmed that:

- To their knowledge, the variations to the component or element of structure, which is the subject of the referenced assessment, have not been subjected to a fire test to the standard against which the referenced assessment is being made.
- They agree to withdraw the referenced assessment from circulation if the component or element of structure is the subject of a fire test by a test authority in accordance with the standard against which the referenced assessment is being made and the results are not in agreement with the referenced assessment.
- They are not aware of any information that could adversely affect the conclusions of the referenced assessment and – if they subsequently become aware of any such information – they agree to ask the assessing authority to withdraw the assessment.

3. Requirements and limitations of the referenced assessment

- The scope of the referenced assessment report is limited to an assessment of the variations to the tested systems described in section 4.3.
- The referenced assessment report details the methods of construction, test conditions and assessed results expected in accordance with AS 1530.4:2014.
- The referenced assessment applies to Advanced Timber Composite (ATC) floor systems exposed to fire from below in accordance with the requirements of AS 1530.4:2014 where horizontal elements must be exposed to heat from the underside only.
- The concrete slab and shear connectors of the ATC floor systems must be designed by a professional structural engineer.
- The size of the timber beams must be designed by a professional structural engineer to meet the structural adequacy criteria considering the effective char depths provided in the referenced assessment report.

[3] European Committee for Standardization, 2010, Extended application reports on the fire performance of construction products and building elements, EN 15725:2010, European Committee for Standardization, Brussels, Belgium

[4] National Construction Code Volumes One and Two - Building Code of Australia 2022, Australian Building Codes Board, Australia

- For ATC floor systems:
  - Without a fire-rated plasterboard ceiling – the timber beams can be spaced at maximum 1200 mm centres.
  - With a fire-rated plasterboard ceiling,
    - the timber beams must be spaced at maximum 600 mm centres, otherwise;
    - the fire rated plasterboards must be installed onto a steel frame with grid of 600 mm × 600 mm.
- Service penetrations can pass through the floor system as long as the fire stopping elements are fixed or installed directly to the concrete surface. If there is a plywood layer present, it must be cut short to accommodate the installation of these fire stopping products – as shown in Figure 2. The referenced assessment report does not assess the fire performance of such penetrations. It's important to note that the referenced assessment report does not evaluate the fire performance of these penetrations. The fire resistance performance of such service penetrations should be obtained from the appropriate passive manufacturer, using the results of tested or assessed services – from an accredited testing authority – in an equivalent thickness concrete floor system.
- The referenced assessment report is only valid for the assessed systems and must not be used for any other purpose. Any changes with respect to size, construction details, loads, stresses, edge or end conditions – other than those identified in the referenced assessment report – may invalidate the findings of the referenced assessment. If there are changes to the system, a reassessment will need to be done by an Accredited Testing Laboratory (ATL) that is accredited to the same nominated standards of the referenced assessment report.
- The documentation that forms the basis for the referenced assessment report is listed in Appendix A of the referenced report.
- The referenced assessment report has been prepared using information provided by others. Warringtonfire has not verified the accuracy and/or completeness of that information and will not be responsible for any errors or omissions that may have been incorporated into the referenced assessment report as a result.
- The referenced assessment is based on the proposed systems being constructed under comprehensive quality control practices and following appropriate industry regulations and Australian Standards on quality of materials, design of structures, guidance on workmanship and expert handling, placing and finishing of the products on site. These variables are beyond the control and consideration of the referenced assessment report.

4. Description of the specimen and variations

4.1 Description of assessed systems

The proposed ATC floor systems are loadbearing composite floor systems which typically consist of timber floor beams / joists, a layer of plywood, shear connectors, reinforcing mesh and a layer of concrete. The sizes of the components vary with the FRL of the floor system. It is proposed to assess the fire resistance performance of the ATC floor system with or without the layer of plywood. For ATC floor systems without the layer of plywood, the plywood could only be removed after the concrete screed layer is fully dried and providing its full effective strength.

4.2 Referenced test data

The assessment of the variation to the tested systems and the determination of the expected performance is based on the results of the fire tests documented in the reports summarised in Table 3. Further details of the tested systems are included in Appendix A of the referenced report. Forest and Wood Products Australia Ltd have granted permission to use their data in the referenced assessment report.

Table 3 Referenced test data

Report number	Test / assessment report sponsor	Test / issued date	Testing / issuing authority
36474400.1	Forest and Wood Products Australia	28 October 2015	Warringtonfire (formerly known as Exova Warringtonfire)
TST180021 R2.0	Forest and Wood Products Australia	6 March 2019	Warringtonfire
FRT220218 R1.0	Australian Sustainable Hardwoods (ASH)	27 January 2023	Warringtonfire
FRT220217 R1.0	Australian Sustainable Hardwoods (ASH)	31 January 2023	Warringtonfire

4.3 Variations to the tested systems

The tested systems and variations to those tested systems – together with the referenced standard fire tests – are described in Table 4.

Table 4 Variations to tested systems

Item	Reference test	Description	Variations
ATC floor system with shining gum GLT beams	FRT220217 R1.0	The test specimen of FRT220217 consisted of a 2950 mm wide × 4250 mm long × 491 mm thick ATC floor system. The floor system was loaded with a load of 7.0 kPa for the first 90 minutes, then reduced to 5.5 kPa after 90 minutes. The meshed concrete layer was 100 mm thick and was installed on top of the 21 mm thick plywood panel. The composite floor was supported by four glued laminated timber beams. The timber beams were made of plantation shining gum timber, with an average density of 592 kg/m^3 and a moisture content of 9.6%. The test was conducted for 121 minutes and in accordance with AS 1530.4:2014.	It is proposed to assess the ATC floor systems with the following variations: • The ATC floor systems made of plantation shining gum glued laminated structural timber beams are capable of achieving FRLs of up to 120/120/120 provided that the exposed GLT beams are designed by a professional structural engineer to meet the structural adequacy criteria considering the effective char depths outlined in Table 6. • The ATC floor systems made of Victorian ash (Eucalyptus regnans) glued laminated structural timber beams are capable of achieving FRLs of up to 120/120/120 provided that the exposed beams are designed by a professional structural engineer to meet the structural adequacy criteria considering the effective char depths outlined in Table 6. • The floor systems, which are protected by fire-rated ceiling, are capable of achieving FRLs of up to 180/180/180. • Minimum concrete layer thickness of 60 mm – as appropriate for various FRLs. • The plywood layer thickness could be between 0 mm to 25 mm as appropriate for various FRLs. • For ATC floor systems without a fire-rated plasterboard ceiling, the timber beams must be spaced at maximum 1200 mm centres. • For ATC floor systems with a fire-rated plasterboard ceiling: – the timber beams must be spaced at maximum 600 mm centres, otherwise; – the fire-rated plasterboards must be installed onto a steel supporting frame with grid of 600 mm × 600 mm. • Service penetrations can pass through the floor system as long as the fire stopping elements are fixed or installed
ATC floor system with Victorian ash GLT beams (MASSLAM 45)	FRT220218 R1.0	The test specimen of FRT220218 consisted of a 2950 mm wide × 4250 mm long × 491 mm thick ATC floor system. The floor system was loaded with a distributed load of 7.5 kPa for the first 90 minutes, then reduced to 6.2 kPa after 90 minutes. The meshed concrete layer was 100 mm thick and was installed on top of the 21 mm thick plywood panel. The composite floor was supported by four glued laminated timber beams. The timber beams were made of Victorian ash (Eucalyptus regnans), with an average density of 647 kg/m^3 and a moisture content of 10.4%. The test was conducted for 121 minutes and in accordance with AS 1530.4:2014.	
ATC floor system protected with a fire-rated plasterboard ceiling	36474400.1 TST180021 R2.0	The test specimen of 36474400.1 consisted of a 2900 mm wide × 4290 mm long × 335 mm thick loadbearing floor-ceiling system with various timber joists. The floor-ceiling system included two layers of 16 mm thick fire-rated plasterboard on the exposed side secured to the joists through furring channels. The test was conducted for a period of 90 minutes and in accordance with AS 1530.4:2005[5]. The test specimen of TST180021 R2.0 consisted of a 2900 mm wide × 4290 mm long × 351 mm thick loadbearing floor-ceiling system incorporating various joints. The floor-ceiling system	

[5] Standards Australia, 2005, Methods for fire tests on building materials, components and structures – Part 4: Fire-resistance tests for elements of construction, AS 1530.4:2005, Standards Australia, NSW.

Item	Reference test	Description	Variations
		included three layers of 16 mm thick fire-rated plasterboard on the exposed side secured to the joists through furring channels. The test was conducted for a period of 120 minutes and in accordance with AS 1530.4:2014.	directly onto the concrete layer. If there is a plywood layer present, it must be cut short to accommodate the installation of these fire stopping products. The referenced assessment report does not assess the fire performance of such penetrations. It's important to note that the referenced assessment report does not evaluate the fire performance of these penetrations. The fire resistance performance of such services should be obtained from the appropriate passive manufacturer, using the results of tested or assessed services – from an accredited testing authority – in an equivalent thickness concrete floor system.

4.4 Schedule of components

Table 5 outlines the schedule of components for the assessed systems. Figure 1 to Figure 2 show the assessed systems.

Table 5 Schedule of components of assessed systems

Item	Description	
Concrete		
1.	Item name	Concrete slab
	Thickness	Refer to Table 6
	Density	Nominal 2400 kg/m^3
	Compressive strength	25 MPa
Reinforcing bar		
2.	Item name	Reinforcing mesh
	Product size	SL62, SL72, SL82 or SL92
Flooring (concrete form)		
3.	Item name	Flooring panel
	Product name	Plywood flooring panel
	Manufacturer	Carter Holt Harvey (CHH)
	Thickness	As outlined in Table 6
	Density	Nominal 550 kg/m^3
	Moisture content	Nominal 12%
Beams		
4.	Item name	Timber beam - 1
	Product name	Plantation shining gum glued laminated timber beams
	Botanical name	Eucalyptus nitens
	Manufacturer	Australian Sustainable Hardwoods (ASH)
	Size	To be designed by a professional structural engineer to meet the structural adequacy criteria considering the effective char depths outlined in Table 6.
	Density	Nominal 590 kg/m^3
	Moisture content	Nominal 12%
	Strength class	SD3
	Adhesive	Henkel PURBOND HBS - Polyurethane Adhesive
5.	Item name	Timber beam - 2
	Product name	Victorian ash glued laminated timber beams (MASSLAM 45)
	Botanical name	Eucalyptus regnans, Eucalyptus delegatensis
	Manufacturer	Australian Sustainable Hardwoods (ASH)
	Size	To be designed by a professional structural engineer to meet the structural adequacy criteria considering the effective char depths outlined in Table 6.
	Density	Nominal 650 kg/m^3
	Moisture content	Nominal 12%
	Strength class	SD3
	Adhesive	Henkel PURBOND HBS - Polyurethane Adhesive

Item	Description	
Fixings		
6.	Item name	Shear screws – Concrete to timber beam connectors
	Product name	M16 galvanised coach screw hex head, partial thread
	Size	Ø16 mm × 200 mm in a staggered manner at 200 mm centres
	Material	Steel
7.	Item name	Plywood beam screws
	Product name	Decking screw, square drive
	Size	10g × 50 mm
	Material	Steel
Installation method		
8.	Installation	• If two pieces of GLT beams are used to manufacturer a wider beam, they are to be glued together using FORTIS® AD 5405 – Polyurethane Adhesive. • The plywood flooring panels (item 3) – if used – are then screw fixed to the top of the timber beams using plywood beam screws (item 7) at 300 mm centres. • Concrete to timber beam shear screws (item 6) are then screw fixed into the top edge of each beam – through the plywood (if installed) – in a staggered manner at 200 mm centres to connect and hold the concrete mass to the timber beams. • The concrete (item 1) is then poured onto the plywood (if installed) around the reinforcement mesh (item 2). • The concrete should be cured for minimum 28 days. • The plywood flooring panels (item 3) can be removed if required after the concrete layer is cured. • For services penetrating through the ATC floor system with plywood installed, the system must be installed as shown in Figure 2. • Refer to Figure 1 and Figure 2 for more details.

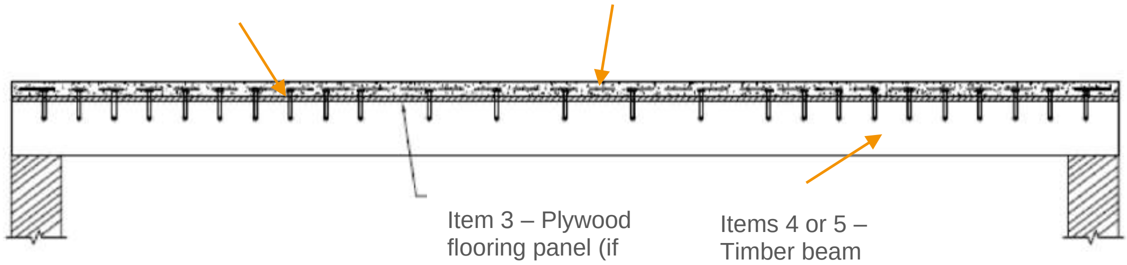


Figure 1 Details of proposed floor systems

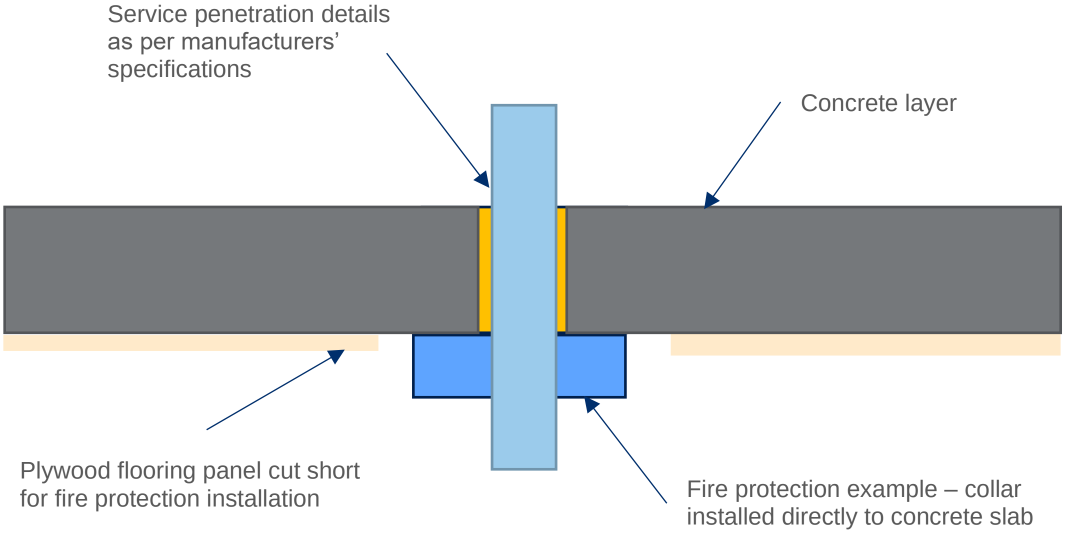


Figure 2 Service penetration of ATC floor systems with plywood (form) floor panel

5. Assessment outcome

Details of the assessment and discussion are only available in the referenced main assessment report. The referenced assessment demonstrates that the proposed Advanced Timber Composite (ATC) floor systems are capable of achieving FRLs shown in Table 6 – in accordance with AS 1530.4:2014.

Table 6 Assessment outcome

Construction	Plywood thickness (mm)	Minimum concrete thickness (mm)	Effective char depths of beams (mm)	Encapsulation	Requirements	FRL
ATC floor system with shining gum glued laminated timber (GLT) beams	ATC floor systems with plywood thickness < 21 mm or no plywood	60	27.2	Exposed timber beams	Plantation shining gum GLT beams must be designed by a professional structural engineer to meet the structural adequacy criteria considering the effective char depths provided in this assessment report.	30/30/30
		80	47.4			60/60/60
		100	67.7			90/90/90
		120	87.9			120/120/120
		120	77.7	2 × 16 mm fire-rated plasterboard ceiling		180/180/180
		120	47.4	3 × 16 mm fire-rated plasterboard ceiling		180/180/180
	ATC floor systems with plywood thickness ≥ 21 mm	60	27.2	Exposed timber beams		30/30/30
		80	47.4			60/60/60
		90	67.7			90/90/90
		110	87.9			120/120/120
		120	77.7	2 × 16 mm fire-rated plasterboard ceiling		180/180/180
		120	47.4	3 × 16 mm fire-rated plasterboard ceiling		180/180/180

Construction	Plywood thickness (mm)	Minimum concrete thickness (mm)	Effective char depths of beams (mm)	Encapsulation	Requirements	FRL
ATC floor system with Victorian ash GLT beam (MASSLAM 45)	ATC floor systems with plywood thickness < 21 mm or no plywood	60	24.7	Exposed timber beams	Victorian ash GLT beams must be designed by a professional structural engineer to meet the structural adequacy criteria considering the effective char depths.	30/30/30
		80	42.4			60/60/60
		100	60.1			90/90/90
		120	77.8			120/120/120
		120	70.1	2 × 16 mm fire-rated plasterboard ceiling		180/180/180
		120	42.4	3 × 16 mm fire-rated plasterboard ceiling		180/180/180
	ATC floor systems with plywood thickness ≥ 21 mm	60	24.7	Exposed timber beams		30/30/30
		80	42.4			60/60/60
		90	60.1			90/90/90
		110	77.8			120/120/120
		120	70.1	2 × 16 mm fire-rated plasterboard ceiling		180/180/180
		120	42.4	3 × 16 mm fire-rated plasterboard ceiling		180/180/180

Notes:

- Concrete slab and shear connectors must be designed by a professional structural engineer.
- The effective char depths of beams shown in this table is for the sides and the bottom face of the timber beams.
- The glued laminated timber beams can be spaced at maximum 1200 mm centres.
- For ATC floor system with a fire-rated plasterboard ceiling:
  - The timber beams must be spaced at maximum 600 mm centres, otherwise;
  - The fire-rated plasterboards must be installed onto a steel supporting frame with a grid of 600 mm × 600 mm.
- Service penetrations can pass through the ATC floor system as long as the fire stopping elements are fixed or installed directly to the concrete surface. If there is a plywood layer present, it must be cut short to accommodate the installation of these fire stopping products. The referenced assessment report does not assess the fire performance of such penetrations. The fire resistance performance of such service penetrations must be established using the results from the relevant passive fire protection supplier for tested or assessed services penetrating a concrete slab of equivalent thickness by an Accredited Testing Authority (ATL) in accordance with AS 1530.4:2014.

6. Validity

Warringtonfire does not endorse the tested or assessed products and systems in any way. The conclusions of the referenced assessment may be used to directly assess fire resistance, but it should be recognised that a single test method will not provide a full assessment of fire resistance under all conditions.

Due to the nature of fire testing and the consequent difficulty in quantifying the uncertainty of measurement, it is not possible to provide a stated degree of accuracy. The inherent variability in test procedures, materials and methods of construction, and installation may lead to variations in performance between elements of similar construction.

The referenced assessment is based on test data, information and experience available at the time of preparation. If contradictory evidence becomes available to the assessing authority, the assessment will be unconditionally withdrawn and the report sponsor will be notified in writing. Similarly, the assessment should be re-evaluated, if the assessed construction is subsequently tested since actual test data is deemed to take precedence.

The procedures for the conduct of tests and the assessment of test results are subject to constant review and improvement. The sponsor is therefore recommended that the referenced assessment report be reviewed on, or before, the stated expiry date.

The referenced assessment represents our opinion about the performance of the proposed systems that is expected to be demonstrated when subjected to test conditions in accordance with AS 1530.4:2014, based on the evidence referred to in the referenced assessment report.

The referenced assessment is provided to Australian Sustainable Hardwoods (ASH) for their own specific purposes. The referenced assessment report may be used as evidence of suitability in accordance with the requirements of the relevant National Construction Code. Building certifiers and other third parties must determine the suitability of the systems described in the referenced assessment report for a specific installation.

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Appendix 2 – Acoustic System Test Reports (Selection)

CSIRO ACOUSTIC MEASUREMENT REPORT

Commonwealth Scientific and Industrial Research Organisation, Infrastructure Technologies
Acoustics Testing Laboratory, Research Way, Clayton, Victoria 3168 Australia

Report No:
TL774-03-2

Client: Australian Sustainable Hardwoods Pty Ltd
4 Weir Road, Heyfield, Vic 3858

Measurement Type: Airborne Sound Insulation

AS 1191-2002 (R2016): *Acoustics – Method for laboratory measurement of airborne sound insulation of building elements.*
AS/NZS ISO 717-1 (2004): *Acoustics – Rating of sound insulation in buildings and of building elements. Part 1: Airborne Sound Insulation*.

Test Specimen

[Specimen area: 3.60 x 3.00 m (w x h) = 10.8 m²]

Description:
- ATC 80/210 mm Concrete/Timber Composite Panel Subfloor
- no floor covering or built-up floor on top
- no ceiling below
- total top-to-bottom footprint approx 290 mm

Components[6]

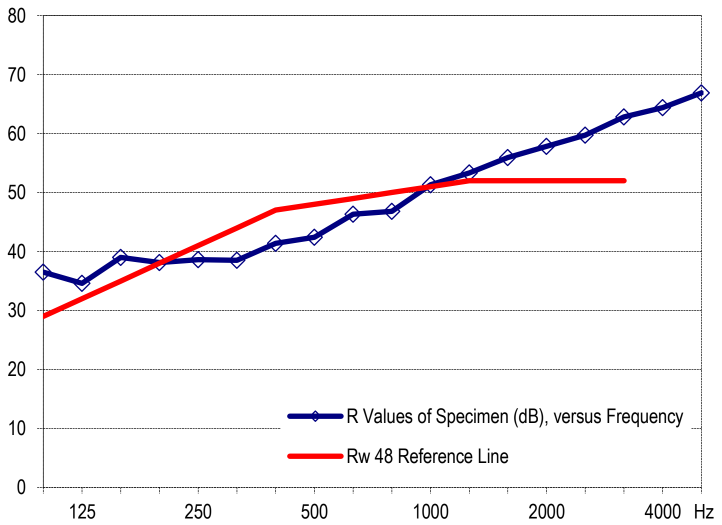
ATC 80/210 Composite Panel: • 80 mm thick reinforced concrete panel, • cast onto a timber structural frame of 65 x 210 mm hardwood; a full-perimeter timber frame being made to fit into the laboratory's 3600 x 3000 mm test-aperture with 10 mm clearance all-around, and full-length joists at 600 mm spacing (nom) across the field of the panel (temporary formwork between the structural joists was removed in this instance, though it might sometimes be left in place permanently), • overall weight 200 kg/m² (approx), • concrete was fully cured (28 days) prior to being transported to the laboratory and installed.

See also photos/images on following page(s) of this report.

Installation:
- The ATC composite panel was craned into the laboratory and dropped into the test aperture onto a full perimeter support ledge, with screw-adjustable supports every 150 mm which were adjusted by hand to have some weight being borne on each support. Four holes through the concrete (approx 200 mm from the longer edges; provided for lifting purposes) were closed off from below with a quick-setting filler, then filled to the top with sand, and taped-off top and bottom. The panel stood proud of the surrounding floor of the chamber by approx 140 mm; a skirt of concrete sleepers was installed around the panel, approximately flush in height. The perimeter gap (approx 10 mm) between the panel and the test aperture and the sleepers was filled with fine grain sand.
- Installation was carried out by the client and associates, with some assistance from laboratory staff.

Measurement Details & Results[2]

Frequency (Hz)	Specimen R Value (dB) 1/3 Octave	Whole Octave	95 % Conf δ (dB)
100	36.5		1.7
125	34.6	36.4	1.8
160	39.0		1.3
200	38.1		1.5
250	38.6	38.4	0.7
315	38.5		1.1
400	41.4		0.5
500	42.4	42.9	0.4
630	46.3		0.3
800	46.8		0.6
1000	51.3	49.6	0.3
1250	53.3		0.2
1600	55.9		0.4
2000	57.8	57.5	0.2
2500	59.7		0.4
3150	62.8		0.5
4000	64.4	64.4	0.6
5000	66.9		0.8



Performance Index Numbers
R_w (C; C_{tr}) = 48 (-1; -4) dB
STC = 48

Confidence Intervals (AS 1191, App B, 95 % Confidence)
Measurement was carried out in both directions through the test specimen, using 3 loudspeaker positions in each chamber; giving 6 spatially independent sets of R values, from which average R values and confidence intervals have been calculated (confidence intervals rounded up to 1 decimal place).

Measurement Conditions
Date of measurement: 22 March 2023
200 m³ chamber (upper): 21 °C, 68 % R.H.
100 m³ chamber (lower): 19 °C, 78 % R.H.
Atmospheric pressure: 1006 mBar

Notes, Deviations etc

1. Material details stated are as per client advice; unless identified as (meas), indicating measured by CSIRO.
2. ≥ indicates R values, if any, where measurability was limited by proximity to background level.
3. Specimen area used in calculations was the full area of the specimen aperture, 3.6 x 3.0 m.

Issuing Authority

This report replaces TL774-03-1 which is now withdrawn.

Signed: ……………………………………….
David Truett

Date: 27 October 2023

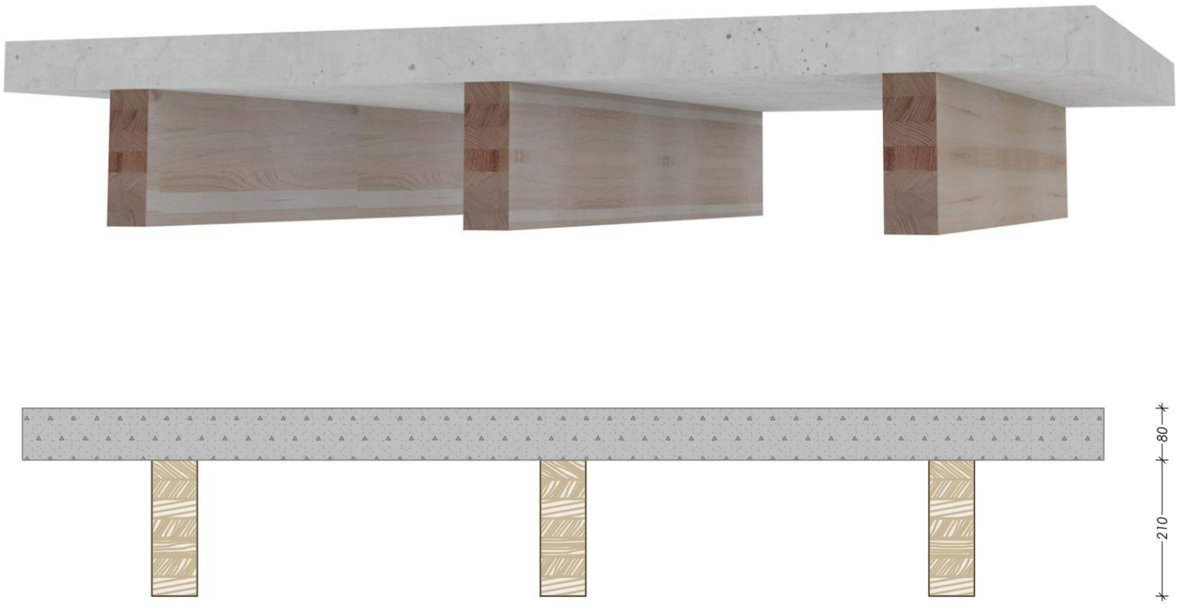
Instrumentation

Real time analyser: • Brüel & Kjær PULSE LAN-XI type 3160-A-4/2
Microphones/preamps: • GRAS type 40AR microphones on GRAS preamps, rotating simultaneously in both rooms with 33 sec period, 1.32 m radius
Noise source: • Norsonic NOR276 and Brüel & Kjær type 4296 dodecahedron loudspeaker driven by a Norsonic NOR280 power amplifier
Calibration: • Brüel & Kjær type 4231 acoustic calibrator: Aug 2022 (NATA cal)
• Analyser: September 2021 (NATA cal)

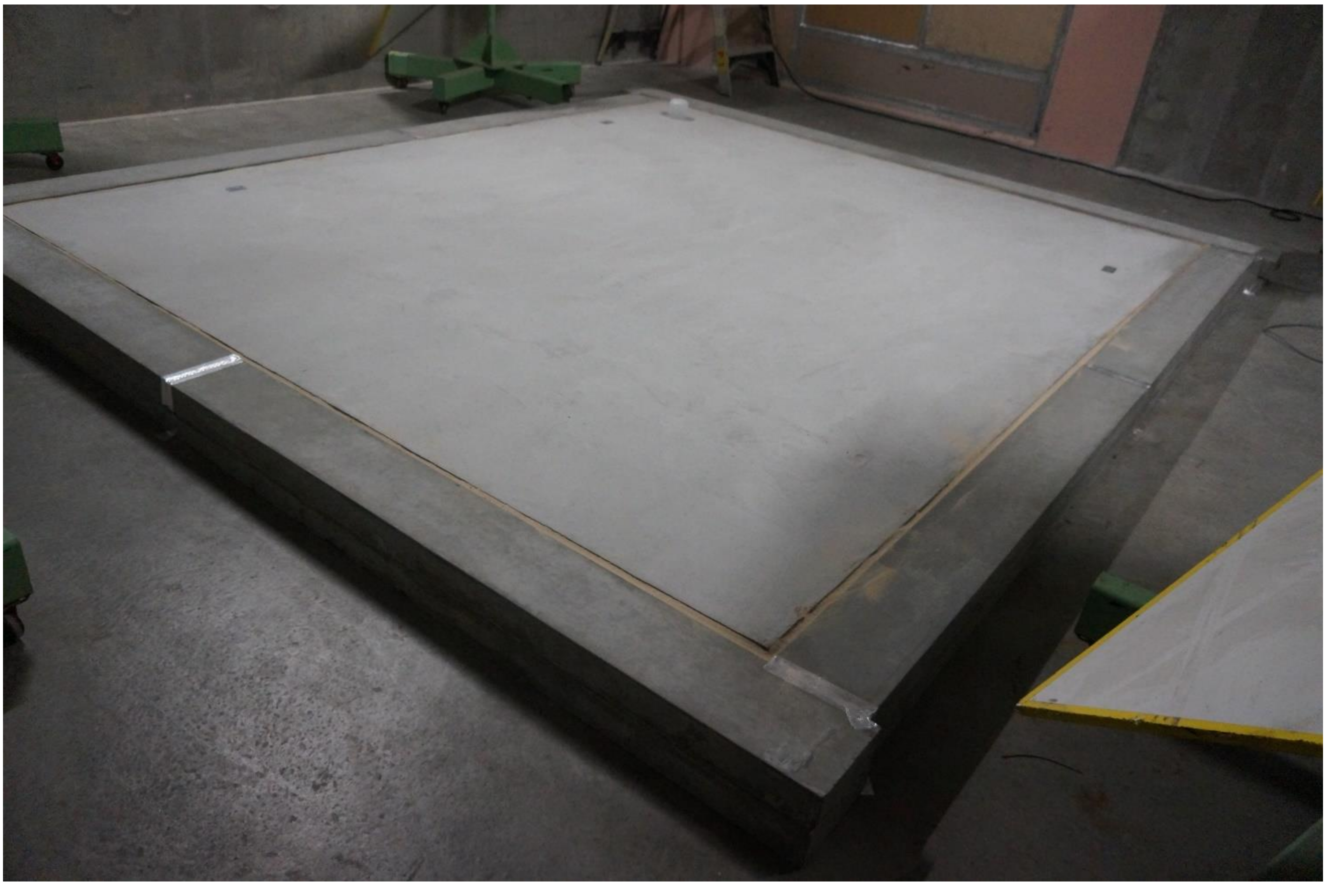
Laboratory Construction

Chambers: • 300 mm thick concrete • rectangular prism with dimensional proportions 1:1.3:1.6 for spectral distribution and overlap of room modes • upper room approx. 200 m³ vol (212 m² area); lower room 100 m³ vol (133 m² area).
Diffusers: • 200 m³ room: 20 diffusers (approx 40 m²) • 100 m³ room: none.
Isolation: • ≥ R_w 80; structurally separate (40 mm air gap), vibration isolated (11 Hz).
Specimen aperture: • 3.60 m wide x 3.00 m high, each chamber having 25 mm thick steel plate lining its 300 mm deep portion of the test aperture, creating a total aperture depth of 640 mm, resilient foam sealing the 40 mm air gap.

Photos/Illustrations of Test Specimen, Construction, and/or Components



Illustrations of complete form-of-construction, as provided by client



ATC Composite Panel, installed in laboratory, with concrete sleeper skirting (as tested)

Photos/Illustrations of Test Specimen, Construction, and/or Components

Underside of ATC Composite Panel, installed in laboratory resting on steel ledge (as tested)

Client: Australian Sustainable Hardwoods Pty Ltd
4 Weir Road, Heyfield, Vic 3858

Measurement Type: Impact Sound Insulation (Floor)

AS ISO 140.6-2006 and ISO 10140 Part 3 (2010): *Laboratory measurement of impact sound insulation of floors.*
AS ISO 717.2 (2004): *Acoustics – Rating of sound insulation in buildings and of building elements. Part 2: Impact sound insulation.*

Test Specimen

[Specimen area: 3.60 x 3.00 m (w x h) = 10.8 m^2]

Description:
- ATC 80/210 mm Concrete/Timber Composite Panel Subfloor
- no floor covering or built-up floor on top
- no ceiling below
- total top-to-bottom footprint approx 290 mm

Components[6]

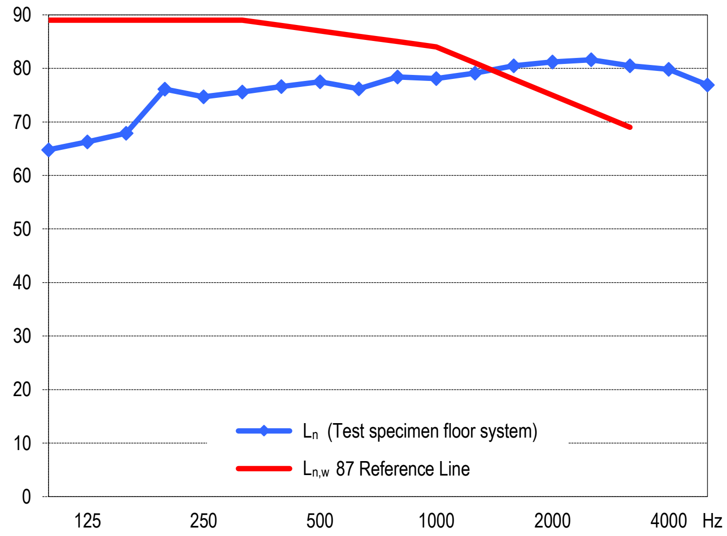
ATC 80/210 Composite Panel: • 80 mm thick reinforced concrete panel, • cast onto a timber structural frame of 65 x 210 mm hardwood; a full-perimeter timber frame being made to fit into the laboratory's 3600 x 3000 mm test-aperture with 10 mm clearance all-around, and full-length joists at 600 mm spacing (nom) across the field of the panel (temporary formwork between the structural joists was removed in this instance, though it might sometimes be left in place permanently), • overall weight 200 kg/m^2 (approx), • concrete was fully cured (28 days) prior to being transported to the laboratory and installed.

See also photos/images on following page(s) of this report.

Installation:
- The ATC composite panel was craned into the laboratory and dropped into the test aperture onto a full perimeter support ledge, with screw-adjustable supports every 150 mm which were adjusted by hand to have some weight being borne on each support. Four holes through the concrete (approx 200 mm from the longer edges; provided for lifting purposes) were closed off from below with a quick-setting filler, then filled to the top with sand, and taped-off top and bottom. The panel stood proud of the surrounding floor of the chamber by approx 140 mm; a skirt of concrete sleepers was installed around the panel, approximately flush in height. The perimeter gap (approx 10 mm) between the panel and the test aperture and the sleepers was filled with fine grain sand.
- Installation was carried out by the client and associates, with some assistance from laboratory staff.

Measurement Details & Results[1,2,3]

Freq. (Hz)	Specimen Floor L_n (dB) 1/3rd Octave	Whole Octave
100	64.8	
125	66.3	71.3
160	67.9	
200	76.1	
250	74.7	80.3
315	75.6	
400	76.6	
500	77.5	81.6
630	76.2	
800	78.4	
1000	78.1	83.3
1250	79.1	
1600	80.5	
2000	81.2	85.9
2500	81.6	
3150	80.5	
4000	79.8	84.1
5000	76.9	



Performance Index Numbers (Laboratory method)
$L_{n,w}$ (C_I) = 87 (-13) dB
IIC[4] = 19 dB

The tapping machine was placed diagonally in eight different locations across the test floor area; sound levels in the room below were measured over a whole microphone rotation (33 sec) at each location,

Measurement Conditions
Date of measurement: 22 March 2023
On top of floor (Upper): 20 °C, 76 % R.H.
Chamber underneath floor (Lower): 19 °C, 78 % R.H.
Atmospheric pressure: 1006 mBar

Notes, Deviations etc

1. ≤ signifies results, if any, where measurement was limited by proximity to background level.
2. L_n = dB re 20 μPa
3. L_n results represent noise levels; i.e. lower = quieter. For IIC results, higher = quieter.
4. IIC is calculated as per ASTM E989-89 but from measurements as per AS ISO 140.6 & ISO 10140 part 3.
5. Testing was carried out unloaded; the weight of the tapping machine being the only load on top of the floor.
6. Material details stated are as per client advice; unless identified as (meas), indicating measured by CSIRO..
7. The test specimen material suffered no visible damage during the course of the test.

Issuing Authority

This report replaces INR301-03-1 which is now withdrawn.

Signed: ....
David Truett

Date: 27 October 2023

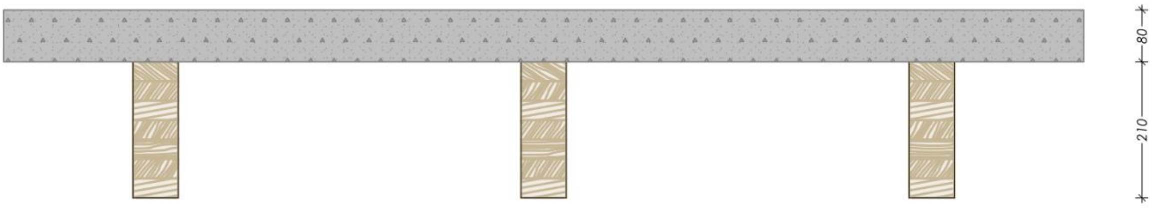
Acoustic Instrumentation

Real time analyser: • Brüel & Kjær PULSE LAN-XI type 3160-A-4/2
Microphone/preamp: • GRAS 46AR microphone/preamp set, rotating continuously with 33 sec period about 1.32 m radius.
Noise source: • Norsonic Nor277 tapping machine
Calibration: • Brüel & Kjær type 4231 Calibrator: Aug 2022 (NATA cal)
• Analyser: Sep 2021 (NATA cal) • Mic/Preamp: Nov 2021 (NATA cal)
• Sensitivity of measurement system was calibrated against the calibrator at the time of measurement.

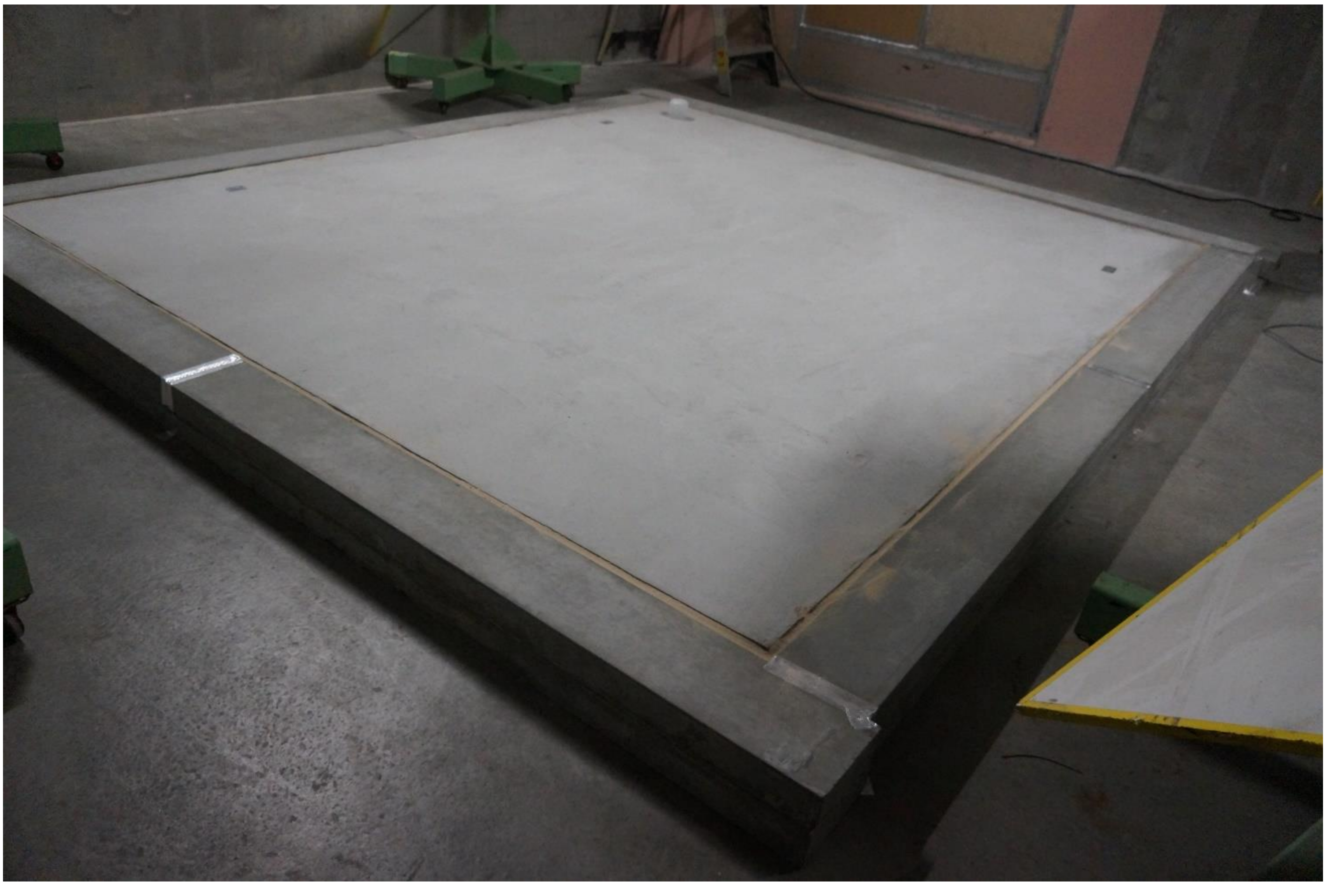
Laboratory Construction

Chambers: • 300 mm thick concrete • parallelepiped with dimensional proportions 1:1.3:1.6 for uniform distribution of room modes
• Source room (Upper): 200 m^3 vol, 212 m^2 surface area (approx.)
• Receiving room (Lower): 105 m^2 vol, 135 m^2 surface area (approx.).
Diffusers: • 200 m^3 room: 20 diffusers (approx 40 m^2) • 100 m^3 room: none.
Specimen aperture: • 3.60 x 3.00 m, each chamber having 25 mm thick steel plate lining its 300 mm deep portion of the test aperture, creating a total aperture depth of 640 mm, resilient foam sealing the 40 mm air gap.

Photos/Illustrations of Test Specimen, Construction, and/or Components



Illustrations of complete form-of-construction, as provided by client



ATC Composite Panel, installed in laboratory, with concrete sleeper skirting (as tested)

Photos/Illustrations of Test Specimen, Construction, and/or Components

Underside of ATC Composite Panel, installed in laboratory resting on steel ledge (as tested)

CSIRO ACOUSTIC MEASUREMENT REPORT

Commonwealth Scientific and Industrial Research Organisation, Infrastructure Technologies
Acoustics Testing Laboratory, Research Way, Clayton, Vic 3168 Australia

Report No: **INR301-01-2**

Client: Australian Sustainable Hardwoods Pty Ltd
4 Weir Road, Heyfield, Vic 3858

Measurement Type: Impact Sound Insulation (Floor)

AS ISO 140.6-2006 and ISO 10140 Part 3 (2010): *Laboratory measurement of impact sound insulation of floors.*
AS ISO 717.2 (2004): *Acoustics – Rating of sound insulation in buildings and of building elements. Part 2: Impact sound insulation.*

Test Specimen

[Specimen area: 3.60 x 3.00 m (w x h) = 10.8 m²]

Description:
- ATC 80/210 mm Concrete/Timber Composite Panel Subfloor
- with floating timber floor on top
- no ceiling below
- total top-to-bottom footprint approx 290 mm plus floating floor thickness

Components[6]

a] ATC 80/210 Composite Panel: • 80 mm thick reinforced concrete panel, • cast onto a timber structural frame of 65 x 210 mm hardwood; a full-perimeter timber frame being made to fit into the laboratory's 3600 x 3000 mm test-aperture with 10 mm clearance all-around, and full-length joists at 600 mm spacing (nom) across the field of the panel (temporary formwork between the structural joists was removed in this instance, though it might sometimes be left in place permanently), • overall weight 200 kg/m² (approx), • concrete was fully cured (28 days) prior to being transported to the laboratory and installed.

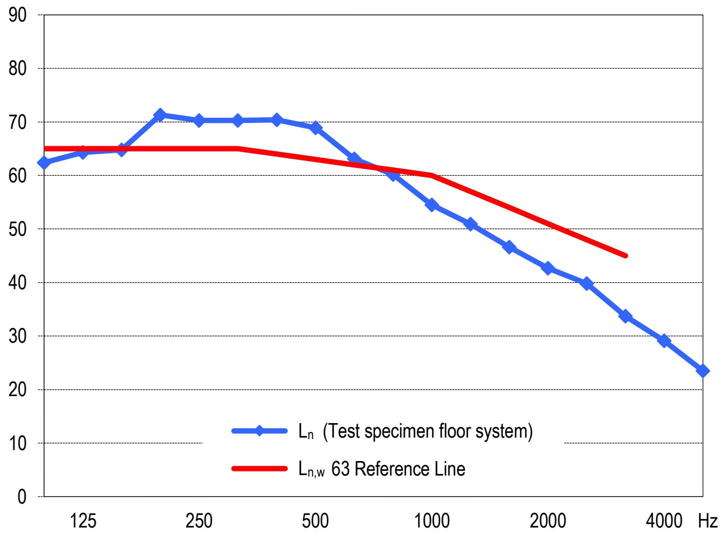
b] Floating timber floor: 14 mm thick French Oak *'Macchiato'* engineered timber planks, on AST ComfortPro SU-220 underlay (2 mm EVA copolymer foam with 80 µm polyethylene moisture barrier film).

See also photos/images on following page(s) of this report.

Installation:
- The ATC composite panel [item a] was craned into the laboratory and dropped into the test aperture onto a full perimeter support ledge, with screw-adjustable supports every 150 mm which were adjusted by hand to have some weight being borne on each support. Four holes through the concrete (approx 200 mm from the longer edges; provided for lifting purposes) were closed off from below with a quick-setting filler, then filled to the top with sand, and taped-off top and bottom. The panel stood proud of the surrounding floor of the chamber by approx 140 mm; a skirt of concrete sleepers was installed around the panel, approximately flush in height. The perimeter gap (approx 10 mm) between the panel and the test aperture and the sleepers was filled with fine grain sand.
- A floating timber floor [item b] was laid on top of the subfloor; underlay was rolled out, cut to size and positioned, then timber planks were cut as required and laid on top of the underlay, mated together with their matching edge profiles, with joins staggered from row to row.
- Installation was carried out by the client and associates, with some assistance from laboratory staff.

Measurement Details & Results[1,2,3]

Freq. (Hz)	Specimen Floor L_n (dB) 1/3rd Octave	Whole Octave
100	62.4	
125	64.3	68.7
160	64.8	
200	71.3	
250	70.3	75.4
315	70.3	
400	70.4	
500	68.9	73.2
630	63.1	
800	60.2	
1000	54.5	61.6
1250	50.9	
1600	46.6	
2000	42.7	48.7
2500	39.8	
3150	33.7	
4000	29.1	35.3
5000	23.5	



Performance Index Numbers (Laboratory method)
$L_{n,w}$ (C_I) = 63 (0) dB
IIC[4] = 47 dB

The tapping machine was placed diagonally in eight different locations across the test floor area; sound levels in the room below were measured over a whole microphone rotation (33 sec) at each location,

Measurement Conditions
Date of measurement: 22 March 2023
On top of floor (Upper): 21 °C, 66 % R.H.
Chamber underneath floor (Lower): 19 °C, 77 % R.H.
Atmospheric pressure: 1007 mBar

Notes, Deviations etc

1. ≤ signifies results, if any, where measurement was limited by proximity to background level.
2. L_n = dB re 20 µPa
3. L_n results represent noise levels; i.e. lower = quieter. For IIC results, higher = quieter.
4. IIC is calculated as per ASTM E989-89 but from measurements as per AS ISO 140.6 & ISO 10140 part 3.
5. Testing was carried out unloaded; the weight of the tapping machine being the only load on top of the floor.
6. Material details stated are as per client advice; unless identified as (meas), indicating measured by CSIRO.
7. The test specimen material suffered no visible damage during the course of the test.

Issuing Authority

This report replaces INR301-01-1 which is now withdrawn.

Signed: ....
David Truett

Date: 27 October 2023

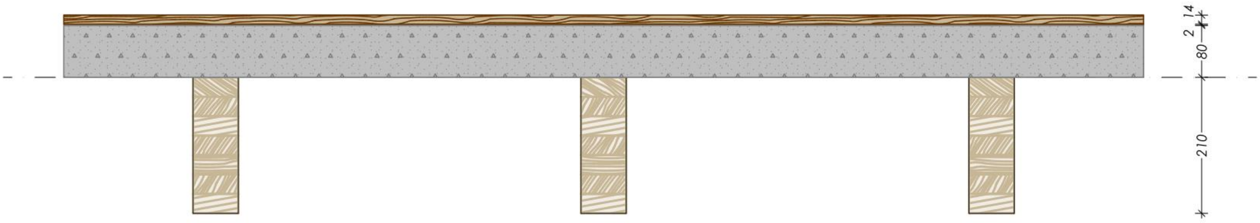
Acoustic Instrumentation

Real time analyser: • Brüel & Kjær PULSE LAN-XI type 3160-A-4/2
Microphone/preamp: • GRAS 46AR microphone/preamp set, rotating continuously with 33 sec period about 1.32 m radius.
Noise source: • Norsonic Nor277 tapping machine
Calibration: • Brüel & Kjær type 4231 Calibrator: Aug 2022 (NATA cal)
• Analyser: Sep 2021 (NATA cal) • Mic/Preamp: Nov 2021 (NATA cal)
• Sensitivity of measurement system was calibrated against the calibrator at the time of measurement.

Laboratory Construction

Chambers: • 300 mm thick concrete • parallelepiped with dimensional proportions 1:1.3:1.6 for uniform distribution of room modes
• Source room (Upper): 200 m³ vol, 212 m² surface area (approx.)
• Receiving room (Lower): 105 m² vol, 135 m² surface area (approx.).
Diffusers: • 200 m³ room: 20 diffusers (approx 40 m²) • 100 m³ room: none.
Specimen aperture: • 3.60 x 3.00 m, each chamber having 25 mm thick steel plate lining its 300 mm deep portion of the test aperture, creating a total aperture depth of 640 mm, resilient foam sealing the 40 mm air gap.

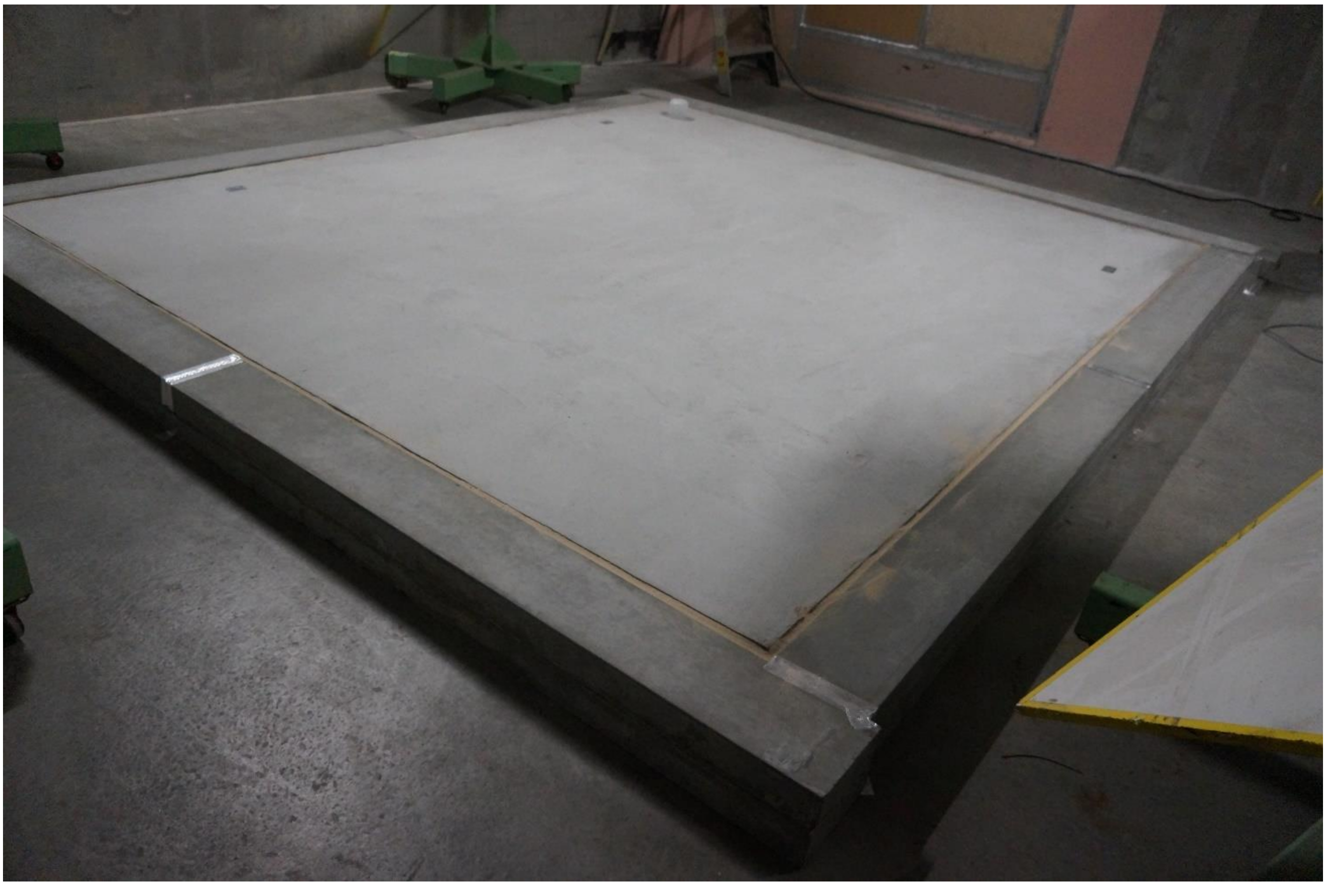
Photos/Illustrations of Test Specimen, Construction, and/or Components



Illustrations of complete form-of-construction, as provided by client

Engineered timber floating floor on top of ATC Composite Panel (as tested)

Photos/Illustrations of Test Specimen, Construction, and/or Components



ATC Composite Panel, installed in laboratory, with concrete sleeper skirting

Underside of ATC Composite Panel, installed in laboratory resting on steel ledge (as tested)

CSIRO ACOUSTIC MEASUREMENT REPORT

Commonwealth Scientific and Industrial Research Organisation, Infrastructure Technologies
Acoustics Testing Laboratory, Research Way, Clayton, Vic 3168 Australia

Report No:
INR301-02-2

Client: Australian Sustainable Hardwoods Pty Ltd
4 Weir Road, Heyfield, Vic 3858

Measurement Type: Impact Sound Insulation (Floor)

AS ISO 140.6-2006 and ISO 10140 Part 3 (2010): *Laboratory measurement of impact sound insulation of floors.*
AS ISO 717.2 (2004): *Acoustics – Rating of sound insulation in buildings and of building elements. Part 2: Impact sound insulation*.

Test Specimen

[Specimen area: 3.60 x 3.00 m (w x h) = 10.8 m^2]

Description:
- ATC 80/210 mm Concrete/Timber Composite Panel Subfloor
- with carpet tile floor covering
- no ceiling below
- total top-to-bottom footprint approx 290 mm plus carpet thickness

Components[6]

a] ATC 80/210 Composite Panel: • 80 mm thick reinforced concrete panel, • cast onto a timber structural frame of 65 x 210 mm hardwood; a full-perimeter timber frame being made to fit into the laboratory's 3600 x 3000 mm test-aperture with 10 mm clearance all-around, and full-length joists at 600 mm spacing (nom) across the field of the panel (temporary formwork between the structural joists was removed in this instance, though it might sometimes be left in place permanently), • overall weight 200 kg/m^2 (approx), • concrete was fully cured (28 days) prior to being transported to the laboratory and installed.

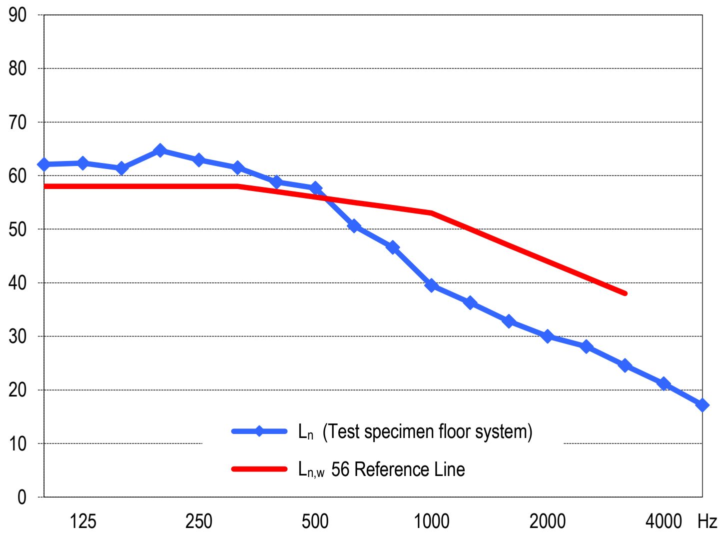
b] 7.5 mm thick commercial loop pile carpet tile planks on top (Godfrey Hirst *'Fractal Ground'*, 3.9 kg/m^2).

See also photos/images on following page(s) of this report.

Installation:
- The ATC composite panel was craned into the laboratory and dropped into the test aperture onto a full perimeter support ledge, with screw-adjustable supports every 150 mm which were adjusted by hand to have some weight being borne on each support. Four holes through the concrete (approx 200 mm from the longer edges; provided for lifting purposes) were closed off from below with a quick-setting filler, then filled to the top with sand, and taped-off top and bottom. The panel stood proud of the surrounding floor of the chamber by approx 140 mm; a skirt of concrete sleepers was installed around the panel, approximately flush in height. The perimeter gap (approx 10 mm) between the panel and the test aperture and the sleepers was filled with fine grain sand.
- Carpet tile planks were laid on top of the concrete face of the panel, covering the entire area of the ATC composite panel floor.
- Installation was carried out by the client and associates, with some assistance from laboratory staff.

Measurement Details & Results[1,2,3]

Freq. (Hz)	Specimen Floor L_n (dB) 1/3rd Octave	Whole Octave
100	62.1	
125	62.3	66.7
160	61.4	
200	64.7	
250	62.9	68
315	61.5	
400	58.8	
500	57.7	61.7
630	50.6	
800	46.6	
1000	39.5	47.7
1250	36.3	
1600	32.8	
2000	30.0	35.5
2500	28.1	
3150	24.6	
4000	21.2	26.7
5000	17.2	



Performance Index Numbers (Laboratory method)
$L_{n,w}$ (C_I) = 56 (0) dB
IIC[4] = 54 dB

The tapping machine was placed diagonally in eight different locations across the test floor area; sound levels in the room below were measured over a whole microphone rotation (33 sec) at each location.

Measurement Conditions
Date of measurement: 22 March 2023
On top of floor (Upper): 21 °C, 68 % R.H.
Chamber underneath floor (Lower): 19 °C, 78 % R.H.
Atmospheric pressure: 1007 mBar

Notes, Deviations etc

1. ≤ signifies results, if any, where measurement was limited by proximity to background level.
2. L_n = dB re 20 μPa
3. L_n results represent noise levels; i.e. lower = quieter. For IIC results, higher = quieter.
4. IIC is calculated as per ASTM E989-89 but from measurements as per AS ISO 140.6 & ISO 10140 part 3.
5. Testing was carried out unloaded; the weight of the tapping machine being the only load on top of the floor.
6. Material details stated are as per client advice; unless identified as (meas), indicating measured by CSIRO.
7. The test specimen material suffered no visible damage during the course of the test.

Issuing Authority

This report replaces INR301-02-1 which is now withdrawn.

Signed: ……………………………………………
David Truett

Date: 27 October 2023

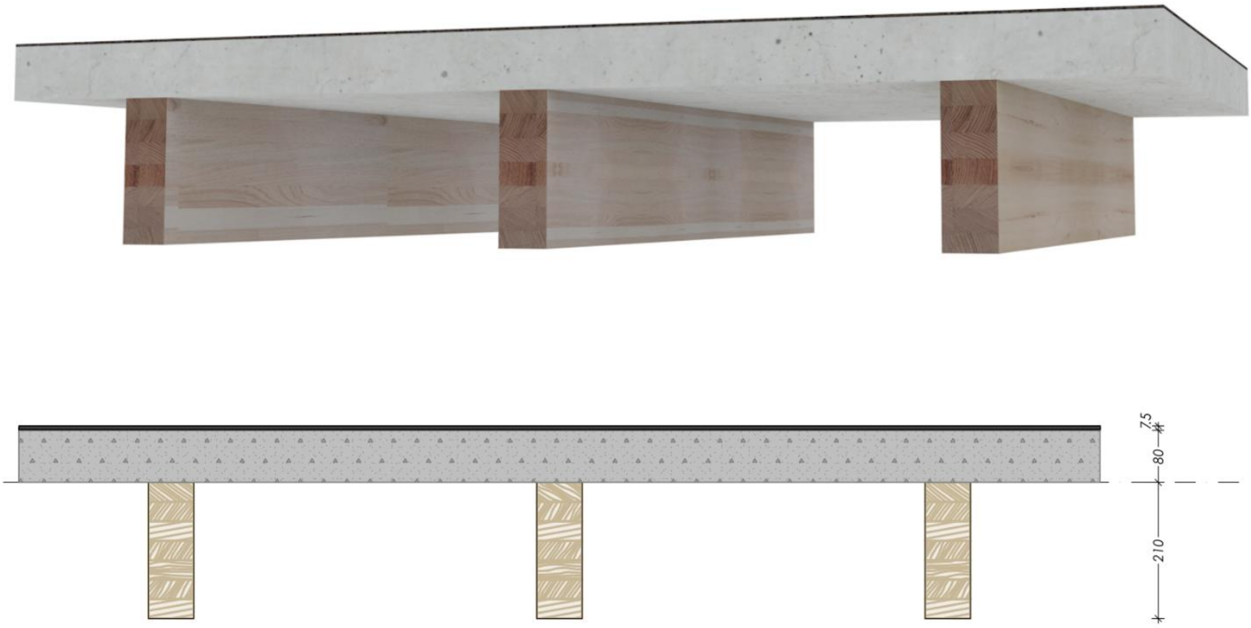
Acoustic Instrumentation

Real time analyser: • Brüel & Kjær PULSE LAN-XI type 3160-A-4/2
Microphone/preamp: • GRAS 46AR microphone/preamp set, rotating continuously with 33 sec period about 1.32 m radius.
Noise source: • Norsonic Nor277 tapping machine
Calibration: • Brüel & Kjær type 4231 Calibrator: Aug 2022 (NATA cal)
• Analyser: Sep 2021 (NATA cal) • Mic/Preamp: Nov 2021 (NATA cal)
• Sensitivity of measurement system was calibrated against the calibrator at the time of measurement.

Laboratory Construction

Chambers: • 300 mm thick concrete • parallelepiped with dimensional proportions 1:1.3:1.6 for uniform distribution of room modes
• Source room (Upper): 200 m^3 vol, 212 m^2 surface area (approx.)
• Receiving room (Lower): 105 m^2 vol, 135 m^2 surface area (approx.).
Diffusers: • 200 m^3 room: 20 diffusers (approx 40 m^2) • 100 m^3 room: none.
Specimen aperture: • 3.60 x 3.00 m, each chamber having 25 mm thick steel plate lining its 300 mm deep portion of the test aperture, creating a total aperture depth of 640 mm, resilient foam sealing the 40 mm air gap.

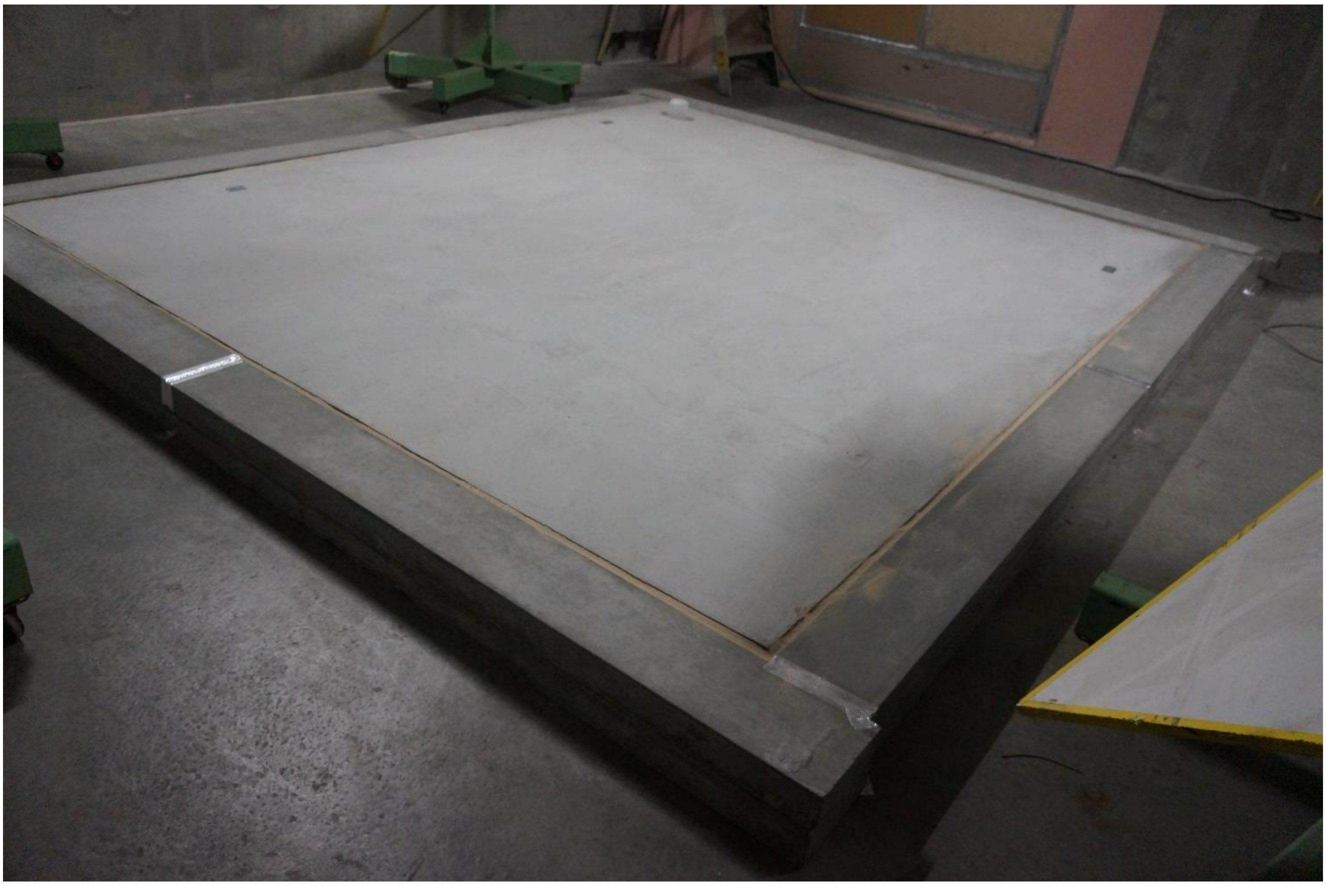
Photos/Illustrations of Test Specimen, Construction, and/or Components



Illustrations of complete form-of-construction, as provided by client

Carpet on top of ATC Composite Panel (as tested)

Photos/Illustrations of Test Specimen, Construction, and/or Components



ATC Composite Panel, installed in laboratory, with concrete sleeper skirting

Underside of ATC Composite Panel, installed in laboratory resting on steel ledge (as tested)

Appendix 3 – Modelled Acoustic System Performance Report

Marshall Day Acoustics Pty Ltd
ABN: 53 470 077 191
10/50 Gipps Street
Collingwood VIC 3066
Australia
T: +613 9416 1855
www.marshallday.com

27 October 2023

TPC Solutions Pty Ltd
Melbourne VIC 3000

Attention: Boris Iskra

Dear Boris,

ATC FLOOR SYSTEM – ESTIMATION OF FLOOR IMPACT AND SOUND TRANSMISSION LOSS PERFORMANCE

Marshall Day Acoustics Pty Ltd (MDA) has been commissioned by TPC Solutions Pty Ltd to provide an estimate of the likely floor impact rating and sound transmission loss performance of several ATC floor systems. Previous estimations have already been carried out under an earlier scope[1]. This letter provides information regarding the second scope of works as detailed below.

Our scope for this part of the project is as follows:

- Review one (1) set of test reports from CSIRO in regard to the laboratory tests conducted for the ATC floor systems
- Incorporate the tested systems in our in-house estimation software to output a prediction of performance
- Review the acoustic performance of the tested systems with various floor surfaces treatments, raised access floors and suspended ceilings within our estimation software. This is limited to seven (7) systems.
- Prepare a summary detailing our findings and recommendations including a table of calculated performances.

We have reviewed the CSIRO tested systems and used the test results to estimate other related floor constructions.

This letter provides test results and new estimations based on the tested systems.

Acoustic terminology is provided in Appendix A.

ESTIMATION METHOD

We have based our estimate of floor impact and sound transmission loss on established theoretical and empirical methods, in conjunction with reference to other test results of similar constructions.

Further estimations are provided by our in-house software, INSUL, which is a program for predicting the sound insulation of walls, floors, ceilings and windows. The program uses prediction theory and comparisons to actual constructions to provide realistic estimates of the sound insulation performance.

[1] Lt 001 R01 20220711 *ATC Floor System – Estimations*, dated 20 January 2023

The performance estimates provided below are intended to be equivalent to the product under test in a laboratory environment to the following standards:

- ISO 10140-2:2021 *Acoustics – Laboratory measurement of sound insulation of building elements – Part 2: Measurement of airborne sound insulation*
- ISO 10140-3:2021 *Acoustics – Laboratory measurement of sound insulation of building elements – Part 3: Measurement of impact sound insulation*
- ISO 717-1:2020 *Acoustics – Rating of sound insulation in buildings and of building elements – Part 1: Airborne sound insulation*
- ISO 717-2:2020 *Acoustics – Rating of sound insulation in buildings and of building elements – Part 2: Impact sound insulation.*

The estimated sound insulation performance has been predicted based on knowledge of acoustic test data for similar systems and proprietary sound insulation prediction software with a quoted accuracy of +/- 3 dB.

NATIONAL CONSTRUCTION CODE (NCC)

For reference we present the requirements of the NCC. It is the applicable legislative document specifying acoustic performance of residential buildings. The current version detailed below is from the NCC 2022 and a Class 2 building classification for the residential component. The NCC requirements summarised below are the mandatory sound insulation criteria for a residential development. Where more stringent criteria are shown, these refer to the MDA recommendations.

Inter-tenancy walls sound insulation

The minimum NCC acoustic requirements for inter-tenancy walls and floors are summarised in Table 1. The green criteria are for flooring and therefore relevant for this document.

Table 1: NCC (class 2 or 3) inter-tenancy sound insulation requirements

Description	Sound insulation rating: Laboratory	Sound insulation rating: On-site	Notes
Wall separating habitable rooms	$R_w + C_{tr} \geq 50$	$D_{nT,w} + C_{tr} \geq 45$	Discontinuous construction not required
Wall separating wet areas	$R_w + C_{tr} \geq 50$	$D_{nT,w} + C_{tr} \geq 45$	Discontinuous construction not required
Wall separating a wet area or kitchen and a habitable room	$R_w + C_{tr} \geq 50$	$D_{nT,w} + C_{tr} \geq 45$	Discontinuous construction required*
Wall separating a sole-occupancy unit from a stairway, public corridor, public lobby, etc	$R_w \geq 50$	$D_{nT,w} \geq 45$	Discontinuous construction not required, but recommended for stairway
Wall separating a sole-occupancy unit from a plant room or lift shaft	$R_w \geq 50$	$D_{nT,w} \geq 45$	Discontinuous construction required*
Floor separating sole-occupancy units	$R_w + C_{tr} \geq 50$ $L_{n,w} \leq 62$ $L_{n,w} \leq 50\text{-}55$	$D_{nT,w} + C_{tr} \geq 45$ $L_{nT,w} \leq 62$ $L_{nT,w} \leq 50\text{-}55$	Floor impact isolation required NCC minimum requirement MDA recommended for residential projects**
Floor separating a sole-occupancy unit from a plant room, lift shaft, stairway, public corridor, public lobby, etc	$R_w + C_{tr} \geq 50$ $L_{n,w} \leq 62$ $L_{n,w} \leq 50\text{-}55$	$D_{nT,w} + C_{tr} \geq 45$ $L_{nT,w} \leq 62$ $L_{nT,w} \leq 50\text{-}55$	Floor impact isolation required NCC minimum requirement MDA recommended for residential projects
Door separating a sole-occupancy unit from a public corridor, public lobby, etc	$Rw \geq 30$	$D_{nT,w} \geq 25$	-

* Discontinuous construction is defined in Part F5.3(c) as having a minimum 20 mm cavity between 2 separate leaves, and

(i) for masonry, where wall ties are required to connect leaves, the ties are of the resilient type; and
(ii) for other than masonry, there is no mechanical linkage between leaves except at the periphery.

In some cases, the minimum requirements of the NCC and other applicable standards are considered inadequate for dwellings of moderate to high quality. The Association of Australian Acoustical Consultants (AAAC) has established a star rating system which provides guidance relating acoustic criteria and perceived quality for occupants as detailed in *Guideline for Apartment and Townhouse Acoustic Rating* dated June 2017. The star rating system is presented in **Error! Reference source not found.** for reference.

Intertenancy floor impact sound insulation

The NCC requirement for control of floor impact noise between apartment floors is $L_{n,w}$ of not more than 62. A lower rating indicates a better acoustic performance.

While this is the legislated requirement, it is considered inadequate for apartments of even moderate quality and equates to a 2-3 star rating in accordance with the AAAC Star Rating System. To address this, we recommend a floor impact sound insulation performance of $L_{n,w} \leq 50\text{-}55$ between dwellings.

Note that even at this level of performance, footfall noise between dwellings would still be audible.

CSIRO TESTS AND NEW ESTIMATIONS

Test results and new estimations based on the tested systems are provided in Appendix C.

We provide ratings that can be directly compared to the NCC criteria and MDA recommendations for residential projects as detailed above.

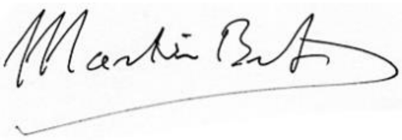
It should be noted that for commercial developments such as between office levels or commercial premises, there is no NCC requirement regarding acoustics. However MDA's recommendation is for a basic separation of at least R_w 50 and $L_{n,w}$ 62.

For estimations that include the 21 mm plywood interlayer under the concrete, it should be noted that the estimations hold true for plywood densities in the range 500-700 kg/m^3. This range includes radiata pine and hardwood based plywoods. Lower than 500 kg/m^3 will result in a gradual drop in performance whilst conversely a density in excess of 700 kg/m^3 will see the performance gradually rise slightly.

Yours faithfully

MARSHALL DAY ACOUSTICS PTY LTD

Martin Butyn



Associate

APPENDIX A ACOUSTIC TERMINOLOGY

R_w	Weighted Sound Reduction Index A single number rating of the sound insulation performance of a specific building element. Rw is measured in a laboratory. Rw is commonly used by manufacturers to describe the sound insulation performance of building elements such as plasterboard and concrete.
R'_w	Apparent Weighted Sound Reduction Index Similar to the Rw value except that measurements are conducted in the field. Building tolerances and flanking noise have an effect on the performance of a partition when it is actually installed, which result in R'w values lower than the laboratory derived Rw values.
$D_{nT,w}$	Weighted Standardised Level Difference A single number rating of the sound level difference between two rooms. $D_{nT,w}$ is typically used to measure the on-site sound insulation performance of a building element such as a wall, floor or ceiling.
$L_{n,w}$	Weighted, Normalized Impact Sound Pressure Level A single number rating of the impact sound insulation of a floor/ceiling when impacted on by a standard 'tapper' machine. $L_{n,w}$ is measured in a laboratory. The lower the $L_{n,w}$, the better the acoustic performance.
$L'_{nT,w}$	Weighted, Standardised Impact Sound Pressure Level A single number rating of the impact sound insulation of a floor/ceiling when impacted on by a standard 'tapper' machine. $L'_{nT,w}$ is measured on site. The lower the $L'_{nT,w}$, the better the acoustic performance.
C_{tr}	A sound insulation adjustment, commonly used with Rw and $D_{nT,w}$. C_{tr} adjusts for low frequency noise, like noise from trucks and subwoofers. C_{tr} values typically range from about -4 to about -12. This term is used to provide information about the acoustic performance at different frequencies, as part of a single number rating system.
C_I	An impact sound insulation adjustment (spectrum adaptation term) for footfall noise. Commonly used with $L_{n,w}$ and $L'_{nT,w}$. This term is used to provide information about the acoustic performance at different frequencies, as part of a single number rating system.

APPENDIX B AAAC STAR RATING SYSTEM

Acoustic design criteria for the project have been developed with reference to the minimum requirements of the NCC and other applicable standards, guidelines and legislation.

In some cases, the minimum requirements of the NCC and other applicable standards are considered inadequate for dwellings of moderate to high quality. The Association of Australian Acoustical Consultants (AAAC) Guideline for Apartment and Townhouse Acoustic Rating, Version 1.0, dated June 2017, has established a star rating system which provides guidance relating acoustic criteria and perceived quality for occupants. These guidelines have been considered in establishing the acoustic design criteria detailed below.

In terms of intertenancy airborne sound reduction between adjacent apartments, a 4-star rating is approximately equivalent to the current NCC requirements.

Table 2 provides a subjective indication of the level of airborne sound insulation expected for each of the star ratings and Table 3 provides the criteria in terms of the in-situ airborne sound insulation performance. Table 3 also includes criteria in relation to floor impact isolation.

Table 2: AAAC acoustic star rating performance summary

	Sound Insulation expressed as $D_{nT,w} + C_{tr}$				
	35	40	45	50	55
Type Of Noise Source	2 Star	3 Star	4 Star	5 Star	6 Star
Normal Speech	Audible	Just Audible	Not Audible	Not Audible	Not Audible
Raised Speech	Clearly Audible	Audible	Just Audible	Not Audible	Not Audible
Dinner Party/ Laughter	Clearly Audible	Audible	Just Audible	Not Audible	Not Audible
Shouting	Clearly Audible	Clearly Audible	Audible	Just Audible	Not Audible
Small Television/ Small Entertainment System	Clearly Audible	Clearly Audible	Audible	Just Audible	Not Audible
Large Television/ Large Hi-fi Music System	Clearly Audible	Clearly Audible	Clearly Audible	Audible	Just Audible
DVD With Surround Sound	Clearly Audible	Clearly Audible	Clearly Audible	Audible	Audible
Digital Television With Surround Sound	Clearly Audible	Clearly Audible	Clearly Audible	Audible	Audible

Table 3: AAAC acoustic star rating summary - intertenancy sound insulation criteria

Intertenancy Activities	2 Star	3 Star	4 Star	5 Star	6 Star
(a) Airborne Sound Insulation For Walls And Floors					
Between Separate Tenancies $D_{nT,w} + C_{tr} \geq$	35	40	45	50	55
Between A Lobby/Corridor & Bedroom $D_{nT,w} + C_{tr} \geq$	30	40	40	45	50
Between A Lobby/Corridor & Living Area $D_{nT,w} + C_{tr} \geq$	25	40	40	40	45
(b) Corridor, Foyer To Living Space Via Door(s) $D_{nT,w} \geq$	20	25	30	35	40
(c) Impact Isolation Of Floors					
Between Tenancies $L_{nT,w} \leq$	65	55	50	45	40
Between All Other Spaces & Tenancies $L_{nT,w} \leq$	65	55	50	45	40
(d) Impact Isolation Of Walls					
Between Tenancies	No	Yes	Yes	Yes	Yes
Between Common Areas & Tenancies	No	No	No	Yes	Yes

The AAAC Star Rating system also includes internal noise level criteria for bedrooms and other habitable rooms due to external noise intrusion and internal building services and appliances, as shown in Table 4.

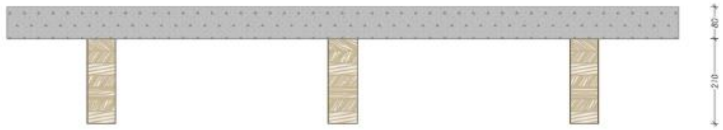
Table 4: AAAC acoustic star rating summary – external noise intrusion

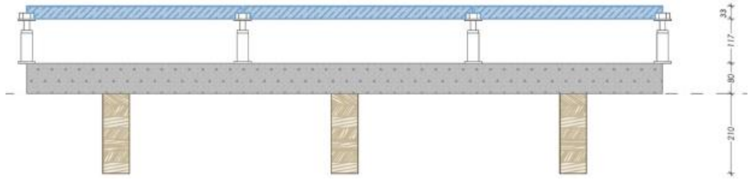
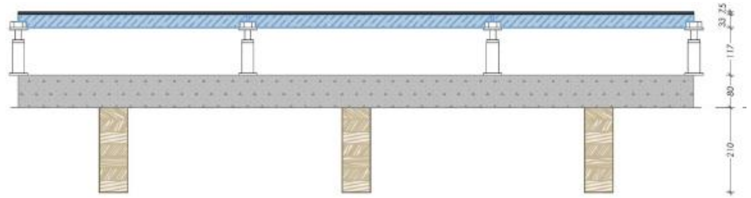
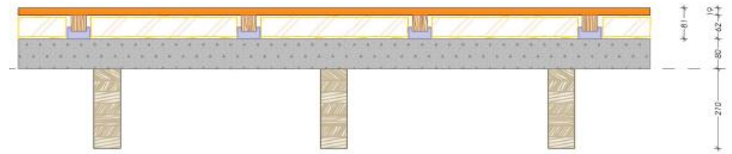
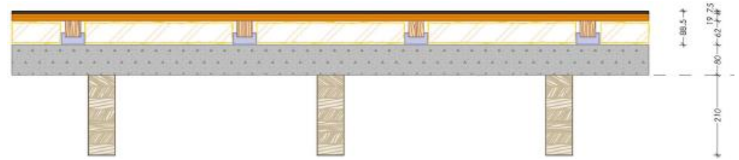
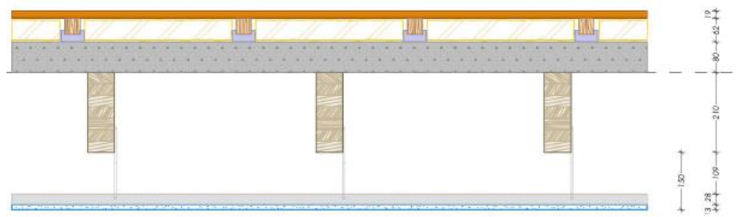
External Noise Intrusion	2 Star	3 Star	4 Star	5 Star	6 Star
(a) Bedrooms					
Continuous Noises $L_{Aeq} \leq$	36dB(A)	35dB(A)	32dB(A)	30dB(A)	27dB(A)
Intermittent Noises $_{ave}$ $L_{Amax} \leq$	50dB(A)	50dB(A)	45dB(A)	40dB(A)	35dB(A)
(b) Other Habitable Rooms Including Open Kitchens					
Continuous Noises $L_{Aeq} \leq$	41dB(A)	40dB(A)	37dB(A)	35dB(A)	32dB(A)
Intermittent Noises $_{ave}$ $L_{Amax} \leq$	55dB(A)	55dB(A)	50dB(A)	45dB(A)	40dB(A)

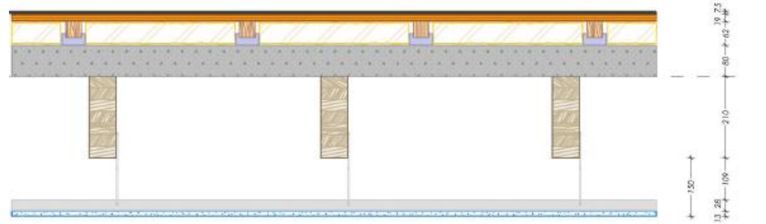
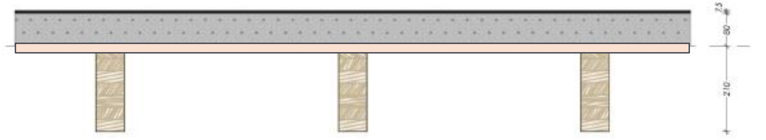
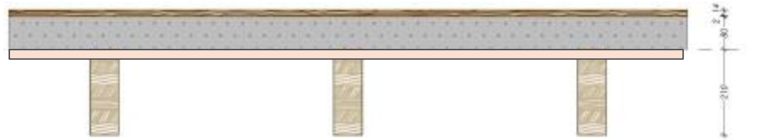
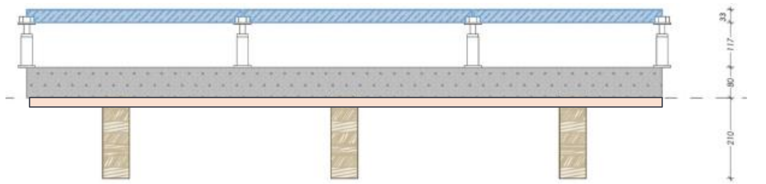
APPENDIX C ESTIMATION RESULTS

Green highlights indicate compliance with the NCC requirements with either the airborne ($R_w + C_{tr}$ 50) or impact ($L_{n,w}$ ≤62) requirements.

Table 5: Estimation results

Ref		ATC Floor System and Surface Treatments	Airborne (R_w)	Airborne ($R_w + C_{tr}$)	Impact ($L_{n,w}$)	Schematic of system
1	a	80 mm bare concrete slab	48	44	87	
	b	120 mm bare concrete slab	51	48	80	
	c	150 mm bare concrete slab	54	49	78	
	d	180 mm bare concrete slab	56	50	75	
2	a	80 mm concrete slab *plus* 7.5 mm carpet	48	44	56	
	b	120 mm concrete slab *plus* 7.5 mm carpet	51	48	51	
	c	180 mm concrete slab *plus* 7.5 mm carpet	56	50	49	
3	a	80 mm concrete slab *plus* 2 mm foam underlay *plus* 14 mm floating timber flooring	50	47	63	
	b	120 mm concrete slab *plus* 2 mm foam underlay *plus* 14 mm floating timber flooring	54	50	59	
	c	180 mm concrete slab *plus* 2 mm foam underlay *plus* 14 mm floating timber flooring	60	54	57	

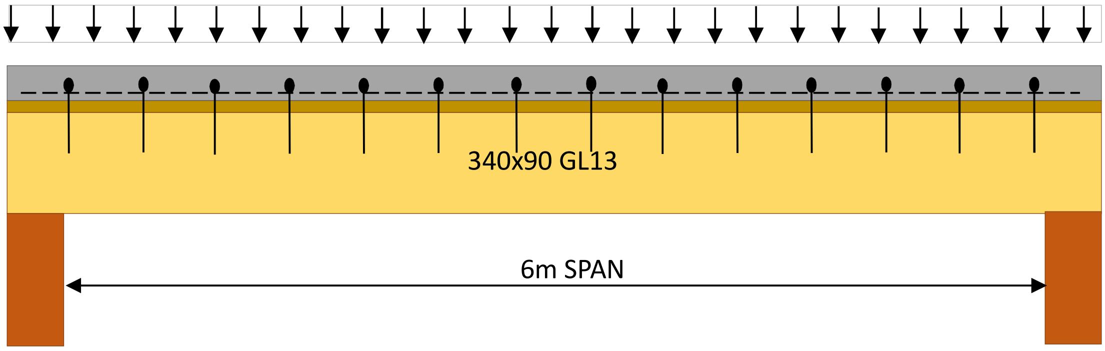
Ref		ATC Floor System and Surface Treatments	Airborne (R_w)	Airborne ($R_w + C_{tr}$)	Impact ($L_{n,w}$)	Schematic of system
4	a	80 mm concrete slab *plus* ASP™ IconX Access Floor	50	43	62	
	b	180 mm concrete slab *plus* ASP™ IconX Access Floor	56	50	56	
5	a	80 mm concrete slab *plus* ASP™ IconX Access Floor *plus* 7.5 mm carpet tile	50	43	54	
	b	180 mm concrete slab *plus* ASP™ IconX Access Floor *plus* 7.5 mm carpet tile	56	50	52	
6	a	80 mm concrete slab *plus* Batten & Cradle™	57	52	51	
	b	120 mm concrete slab *plus* Batten & Cradle™	60	54	48	
7	a	80 mm concrete slab *plus* Batten & Cradle™ *plus* 7.5 mm carpet tile	57	52	45	
8	a	80 mm concrete slab *plus* Batten & Cradle™ *plus* suspended 13 mm plasterboard ceiling	67	58	45	

Ref		ATC Floor System and Surface Treatments	Airborne (R_w)	Airborne ($R_w + C_{tr}$)	Impact ($L_{n,w}$)	Schematic of system
9	a	80 mm concrete slab *plus* Batten & Cradle™ *plus* 7.5 mm carpet tile *plus* 13 mm suspended plasterboard ceiling	67	58	40	
10	a	80 mm concrete on 21 mm ply *plus* 7.5 mm carpet	49	44	54	
	b	120 mm concrete on 21 mm ply *plus* 7.5 mm carpet	52	48	51	
	c	180 mm concrete on 21 mm ply *plus* 7.5 mm carpet	57	50	49	
11	a	80 mm concrete on 21 mm ply *plus* 2 mm foam underlay *plus* 14 mm floating timber flooring	51	47	62	
	b	120 mm concrete on 21mm ply *plus* 2 mm foam underlay *plus* 14 mm floating timber flooring	55	52	59	
	c	180 mm concrete on 21mm ply *plus* 2 mm foam underlay *plus* 14 mm floating timber flooring	60	56	57	
12	a	80 mm concrete on 21mm ply *plus* ASP™ IconX Access Floor	50	43	61	
	b	180 mm concrete on 21mm ply *plus* ASP™ IconX Access Floor	56	50	56	

Appendix 4 – ATC Floor System Design Examples

TIMBER CONCRETE COMPOSITE WORKED EXAMPLE – FRL 0/0/0

This worked example will consider an office situation with a 3 kPa Live load and a 0.5 kPa superimposed dead load, typical of an office environment. No FRL will be considered in this case. The ATC assembly will comprise of 340x90 GL13 glulam beam at 800cts with a 100mm thick concrete structural topping with SL62 bottom on a 21mm F7 plywood sheet.



GEOMETRIC DATA

Beam spacing	800 mm	CONNECTOR	M12 CS @ 90 deg
Slab Depth	100 mm	Spacing inner	125 mm
Joist Depth	340 mm	Embedment	100 mm
Joist Width	90 mm	Slip Modulus Kser	4,554 N/mm
Plywood thickness	21 mm		

MATERIAL DATA

Material/property	GRADE	MOE	f'b	f't	f'c	f'v	phi	DENSITY
Concrete	25	26,669	25	3.0	25	0.44	0.8	2500
Timber web	GL13	13,300	33	16	26	4.2	0.9	550
Plywood	F7	7,900	20	12	15	4.2	0.85	500

LOADING

DEAD LOAD

- SLAB	2.45 kPa		WDL = 1.96 kN/m
- SUPERIMPOSED	0.50 kPa		WDL = 0.40 kN/m
- JOIST			WDL = 0.17 kN/m
- PLYWOOD	0.12 kPa		WDL = 0.09 kN/m
		Total	**WDL = 2.62 kN/m**

Load factors	
Ys =	0.7
Yl =	0.4
Yc =	0.6

LIVE LOAD

- LIVE LOAD INSERVICE 3.00 kPa WDL = 2.40 kN/m

SERVICEABILITY		STRENGTH	
short term			
w serv (wdl) =	2.62 kN/m	1.35DL	3.54 kN/m
w serv (0.7ll) =	1.68 kN/m	1.2DL+1.5LL	6.74 kN/m
long term			
w serv (wdl+0.4ll) =	3.58 kN/m		

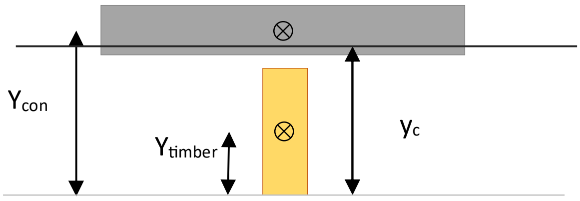
SERVICEABILITY DESIGN

Neutral Axis Calculations - full composite

Plywood ignored in calculation, section properties based on space between timber beam and concrete slab.

Material/Property	i	y	A	MOE	Ixx	EIxx	EA(yc-y)^2
Concrete	1	411.0	80,000	26,669	$66.7\text{x}10^6$	$1.78\text{x}10^{12}$	$3.180\text{x}10^{12}$
WEB	2	170.0	30,600	13,300	$294.8\text{x}10^6$	$3.92\text{x}10^{12}$	$1.667\text{x}10^{13}$

Centroid of section calculated using modular ratio method.



modular ratio = 26,669/13,300 = 2.0052

y_c = (2.0052 x 80,000 x 411 + 30,600 x 170) / (2.0052 x 80,000 + 30,600)

y_c = 372.4 mm

EI_{full} = sum(EIxx + A(y-y_c)

= (26,669 x $66.7\text{x}10^6$) + 26,669x80,000$(411\text{-}372.4)^2$ + (13,300 x $294.8\text{x}10^6$) + 13,300x30,600x$(372.4\text{-}170)^2$

EI_{full} = $2.55\text{x}10^{13}$ Nmm^2

Composite System Properties - slip included.

The Gamma method has been adopted to determine the composite system bending stiffness. This method takes into account the connector stiffness and utilises a γ, which ranges between 0 (no composite action) and 1 (full composite action).

$$\gamma 1 = \frac{1}{1+\frac{}{Ks}}$$

$\gamma 2 = 1.0$, s_{eff} = fastener spacing

$(EI)_{eff} = E_1I_1 + E_2I_2 + \gamma 1 E_1A_1a_1^2 + \gamma 2 E_2A_2a_2^2$

short term deflection

Material/Property	i	y	A	MOE	Ixx	EIxx	γ I	a_i	γ iEAa_i^2	Kser
Concrete	1	411.0	80,000	26,669	$6.67\text{x}10^7$	$1.78\text{x}10^{12}$	0.0586	184.4	$4.250\text{x}10^{12}$	
Connection										4,554
Web	2	170.0	30,600	13,300	$2.948\text{x}10^8$	$3.92\text{x}10^{12}$	1.0000	56.6	$1.306\text{x}10^{11}$	

$$\gamma 1 = \frac{1}{1+\frac{\pi^2\ 26{,}669 \times 80{,}000\ \times 125}{4{,}554\ \times 6000^2}}$$

$\gamma 1 = 0.0586$

y_c = 226.6 mm

(EI)eff = $1.13\text{x}10^{13}$ Nmm2

Efficency = 0.44 (compared to full composite)

Deflection Wdl **= 3.93 mm** SPAN/ 1528 adequate

Deflection 0.7Wll **= 2.52 mm** SPAN/ 2382 adequate

long term deflection

As per short deflection the gamma method is adopted to determine the system bending stiffness. Long term creep factors are used to determine the long term modulus of elasticity. J2 factors adopted from AS1720.1 and AS3600 design codes.

$MOE_{long\ term} = MOE_{short\ term} / j2$

Material/Property	j2	y (mm)	A (mm2)	MOE	Ixx	EIxx	γ i	a_i	$\gamma\ iEAa_i^2$	Ks
Concrete	4.6	411.0	80,000	5,798	$6.67\text{x}10^7$	3.87E+11	0.0872	201.1	$1.6341\text{x}10^{12}$	
Connector	3.0									1,518
Web	2.0	170.0	30,600	6,650	$2.948\text{x}10^8$	$1.96\text{x}10^{12}$	1.0000	39.9	$3.2461\text{x}10^{11}$	

$$\gamma 1 = \frac{1}{1 + \frac{\pi^2\ 5{,}798 \times 80{,}000\ \times 125}{1{,}518\ \times 6000^2}}$$

$\gamma 1 = 0.0872$

yc = 209.9 mm

$(EI)_{eff} = 4.31\text{x}10^{12}$
Efficency = 0.17

Long term deflection = 14.03 mm SPAN/ 428

ULTIMATE DESIGN

Ultimate design adopts 2/3 Kser as the Kultimate and the member actions are calculated based on these section properties. Two load cases are considered due to duration of load effects**.** Member actions are calculated based on a single span system and due to connector slip there are in addition to bending stresses axial forces that need to be considered.

Actions

$f_{t,normal} = \gamma_i E a_i M_{max} / EI_{eff}$

$f_{t,bending} = \pm 0.5 E_{timber} D_{joist} M_{max} / EI_{eff}$

$f_s = 0.5 E B_{joist} D^2_{joist} V_{max} / B_{joist} EI_{eff}$

Ft,normal = phi k1 F't

Ft,bending = phi k1 F'b

1.35DL			1.2DL+1.5LL	
Mmax =	15.91 kNm		*Mmax =*	30.35 kNm
Vmax =	10.61 kN		*Vmax =*	20.23 kN
	γ **1 =** 0.0399		*Ku = 2/3 Ks*	
Ku = 2/3 Ks	γ **2 =** 1.0000			
	a1 = 199.3			
	a2 = 41.7			
	yc = 211.7			
	(EI)eff = 9.78×10^{12}			
Timber			***Timber***	
ft,axial	+0.90 MPa		*ft,normal*	+1.72 MPa
ft,bending	±3.68 MPa		*ft,bending*	±7.01 MPa
Ft,axial	8.21 MPa		Ft,normal	11.52 MPa
Ft,bending	16.93 MPa		Ft,bending	23.76 MPa
Combined	0.33 <1.00		Combined	0.44 <1.00
fs	0.83 MPa		*fs*	1.59 MPa
Fs	2.15 MPa		Fs	3.02 MPa
Ratio	0.39		Ratio	0.53
Concrete			***Concrete***	
fc,normal	-0.34 MPa		*fc,normal*	-0.66 MPa
fc,bending	±2.17 MPa		*fc,bending*	±4.14 MPa
Fc,tension	2.40 MPa		Fc,tension	2.40 MPa
Fc,compression	9.00 MPa		Fc,compression	9.00 MPa
Combined	0.28 <1.00		Combined	0.53 <1.00

If tension in concrete exceeds capacity reinforcement will contribute to capacity.

Shear connector

ØNj = Ø k1 k13 k14 k16 k17 Qlat

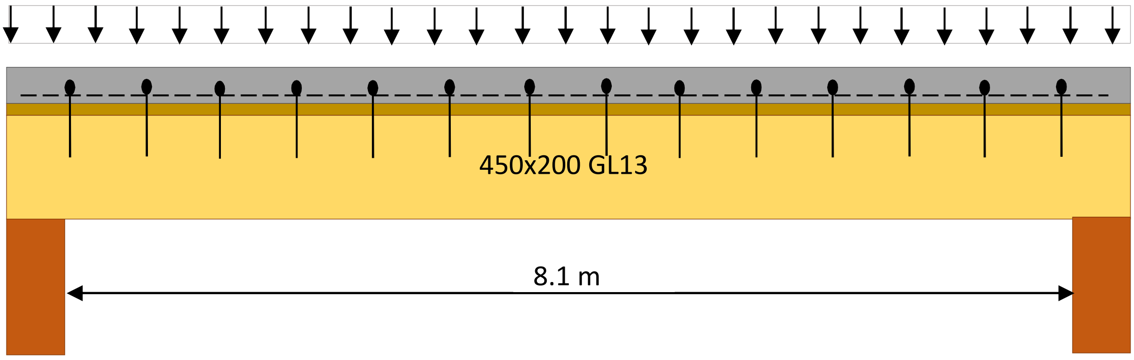
connector M12	M12	CS				
Angle to grain	90	Deg	Joint Group	JD4	phi	0.80
Spacing	125	mm	Qlat	10,100 N	k13	1.00
Embedment	100	mm			k14	1.00
diameter	11.46	mm			k16	1.20
					k17	1.00

1.35DL – k1 0.57	
End fastener	
N* =	2.30
ØNj	5.53
Ratio	0.42

1.2DL+1.5LL - k1=0.69	
End fastener	
N* =	4.38
ØNj	6.69
Ratio	0.65

TIMBER CONCRETE COMPOSITE WORKED EXAMPLE – FRL 90/90/90

This worked example will consider a office building with a 4 kPa Live load and a 1.0 kPa superimposed dead load. FRL 90/90/90 will be considered in this case. The ATC assembly will comprise of 450x200 GL13 glulam beam at 800cts with a 100mm thick concrete structural topping with SL62 bottom on a 17mm F17 plywood sheet.



GEOMETRIC DATA

Beam spacing	800 mm	CONNECTOR	M16 CS @ 90 deg
Slab Depth	100 mm	Spacing	200 mm
Joist Depth	450 mm	Embedment	100 mm
Joist Width	200 mm	Slip Modulus Kser	6,553 N/mm
Plywood thickness	17 mm		

MATERIAL DATA

Material/property	GRADE	MOE	f'b	f't	f'c	f'v	phi	DENSITY
Concrete	32	30,173	32	3.39	32	0.48	0.8	2500
Timber web	GL13	13,300	33	16	26	4.2	0.9	550
Plywood	F17	14,000	50	30	40	6.8	0.85	650

LOADING

DEAD LOAD

- SLAB	2.45 kPa	WDL = 1.96 kN/m
- SUPERIMPOSED	1.00 kPa	WDL = 0.80 kN/m
- JOIST		WDL = 0.49 kN/m
- PLYWOOD	0.11 kPa	WDL = 0.09 kN/m
	Total	**WDL = 3.34 kN/m**

Load factors	
Ys =	0.7
Yl =	0.4
Yc =	0.6

LIVE LOAD

- LIVE LOAD INSERVICE 4.00 kPa WDL = 3.20 kN/m

SERVICEABILITY		STRENGTH	
short term			
w serv (wdl) =	3.34 kN/m	1.35DL	4.50 kN/m
w serv (0.7ll) =	2.24 kN/m	1.2DL+1.5LL	8.80 kN/m
long term			
w serv (wdl+0.4ll) =	4.62 kN/m		

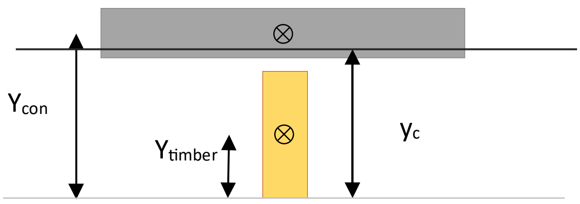
SERVICEABILITY DESIGN

Neutral Axis Calculations - full composite

Plywood ignored in calculation, section properties based on space between timber beam and concrete slab.

Material/Property	i	y	A	MOE	Ixx	EIxx	EA(yc-y)^2
Concrete	1	517.0	80,000	30,173	66.7×10^6	2.01×10^{12}	2.262×10^{13}
WEB	2	225.0	90,000	13,300	1520.0×10^6	20.2×10^{12}	4.561×10^{13}

Centroid of section calculated using modular ratio method



modular ratio = 30,173/13,330 = 2.2686

y_c = (2.2686 x 80,000 x 517 + 90,000 x 225) / (2.2686 x 80,000 + 90,000)

yc = 420.2 mm

EI_{full} = sum(EIxx + EA(y-y_c)

= (30,173 x 66.7×10^6) + 30,173 x 80,000$(517-420.2)^2$ + (13,300 x 1520.0×10^6) + 13,300 x 90,000 x $(420.2-225)^2$

EI_{full} = 9.04×10^{13} Nmm^2

Composite System Properties - slip included.

The Gamma method has been adopted to determine the composite system bending stiffness. This method takes into account the connector stiffness and utilises a γ, which ranges between 0 (no composite action) and 1 (full composite action).

$$\gamma 1 = \frac{1}{1 + \frac{}{Ks}}$$

$\gamma 2 = 1.0$, s_{eff} = fastener spacing

$(EI)_{eff} = E_1 I_1 + E_2 I_2 + \gamma 1 E_1 A_1 a_1^2 + \gamma 2 E_2 A_2 a_2^2$

short term deflection

Material/Property	i	y	A	MOE	Ixx	EIxx	γ I	a_i	γ $iEAa_i^2$	Kser
Concrete	1	517.0	80,000	30,173	6.67×10^7	2.01×10^{12}	0.0827	250.2	1.2508×10^{13}	
Connection										6,553
Web	2	225.0	90,000	13,300	1.52×10^9	2.02×10^{13}	1.0000	41.8	2.0871×10^{12}	

$$\gamma 1 = \frac{1}{1 + \frac{\times 30{,}173 \times 80{,}000 \ \times 200}{6{,}553 \ \times 8100}}$$

$\gamma 1 = 0.0827$

yc = 266.8 mm

(EI)eff = 3.68×10^{13} Nmm2

Efficency = 0.41 (compared to full composite)

Deflection Wdl	**= 5.08 mm**	SPAN/1694 adequate
Deflection 0.7Wll	**= 3.41 mm**	SPAN/2375 adequate

Long term deflection

As per short deflection the gamma method is adopted to determine the system bending stiffness. Long term creep factors are used to determine the long-term modulus of elasticity. J2 factors adopted from AS1720.1 and AS3600 design codes.

$MOE_{long\ term} = MOE_{short\ term} / j2$

Material/Property	j2	y (mm)	A (mm2)	MOE	Ixx	EIxx	γ i	a_i	γ $iEAa_i^2$	Ks
Concrete	4.6	517.0	80,000	6,559	$6.67\text{x}10^7$	$4.37\text{x}10^{11}$	0.1215	263.9	$4.4403\text{x}10^{12}$	
Connector	3.0									2,184
Web	2.0	225.0	90,000	6,650	$1.52\text{x}10^9$	$1.01\text{x}10^{13}$	1.0000	28.1	$4.7307\text{x}10^{11}$	

$$\gamma 1 = \frac{1}{1 + \frac{\times 6{,}559 \times 80{,}000 \ \times 200}{2{,}184 \ \times 8100}}$$

$$\gamma 1 = 0.1215$$

yc = 253.1 mm

(EI)eff = 1.55 $\text{x}10^{13}$
Efficency = 0.17

Long term deflection = 16.75 mm SPAN/ 484

ULTIMATE DESIGN

Ultimate design adopts 2/3 Kser as the Kultimate and the member actions are calculated based on these section properties. Two load cases are considered due to duration of load effects. Member actions are calculated based on a single span system and due to connector slip there are in addition to bending stresses axial forces that need to be considered.

Actions

ft,normal = γ_i E a_i M_{max} / EI_{eff}

ft,bending = ±0.5 E_{timber} D_{joist} M_{max}/ EI_{eff}

fs = 0.5 E B_{joist} D^2_{joist} V_{max} / B_{joist} EI_{eff}

Ft,normal = phi k1 F't

Ft,bending = phi k1 F'b

1.35DL			1.2DL+1.5LL	
Mmax = Vmax = *Ku = 2/3 Ks*	36.94 kNm 18.24 kN γ **1 =** 0.0567 γ **2 =** 1.0000 *a1* = 262.0 *a2* = 30.0 *yc* = 255.0 **(EI)eff =** 3.27×10^{13}		*Mmax =* *Vmax =* *Ku = 2/3 Ks*	72.20 kNm 54.65 kN
Timber *ft,axial* *ft,bending* Ft,axial Ft,bending Combined *fs* Fs Ratio	 +0.45 MPa ±3.38 MPa 8.21 MPa 16.93 MPa 0.25 <1.00 0.75 MPa 2.15 MPa 0.35		***Timber*** *ft,normal* *ft,bending* Ft,normal Ft,bending Combined *fs* Fs Ratio	 +0.88 MPa ±6.61 MPa 11.52 MPa 23.76 MPa 0.35 <1.00 1.47 MPa 3.02 MPa 0.49
Concrete *fc,normal* *fc,bending* Fc,tension Fc,compression Combined	 -0.51 MPa ±1.70 MPa 2.72 MPa 11.52 MPa 0.19 < 1.00		***Concrete*** *fc,normal* *fc,bending* Fc,tension Fc,compression Combined	 -0.99 MPa ±3.33 MPa 2.72 MPa 11.52 MPa 0.38 < 1.00

If tension in concrete exceeds capacity reinforcement will contribute to capacity.

Shear connector

ØNj = Ø k1 k13 k14 k16 k17 Qlat

connector	M16 CS					
Angle to grain	90 Deg	Joint Group	JD4		phi	0.80
Spacing	200 mm	Qlat	18,200 N		k13	1.00
Embedment	100 mm				k14	1.00
diameter	15.55 mm				k16	1.20
					k17	1.00

1.35DL – k1 0.57	
End fastener	
N* =	4.00
ØNj	9.96
Ratio	0.40

1.2DL+1.5LL - k1=0.69	
End fastener	
N* =	7.83
ØNj	12.06
Ratio	0.65

FIRE DESIGN

FRL 90/90/90
Char rate = 0.70 mm/min (AS1720.4)

$W_{dl+fire}$= wdl + 0.4ll = 4.62 kN/m
Char depth = t_{min} x char rate + 7.0 = 90*0.70 + 7.0 = 70.0mm
Modified section
D_{fire}= 450.0 – 70.0 = 380.0 mm (top surface protected by slab and plywood)
B_{fire}= 200 - 2x70.0 = 60.0 mm (both faces effected by fire)

Ku fire = 2/3 Ks

Material/Property	I	y (mm)	A (mm2)	MOE	Ixx	EIxx	γ i	a_i	γ $iEAa_i^2$	Ks
Concrete	1	447.0	80,000	30,173	6.67×10^7	2.02×10^{12}	0.0567	177.0	4.29×10^{12}	
Connector										4,368
Web	2	190.0	22,800	13,300	2.74×10^8	3.65×10^{12}	1.0000	80.0	1.94×10^{12}	

$$\gamma 1 = \frac{1}{1 + \frac{\times 30{,}173 \times 80{,}000\ \times 200}{4{,}368\ \times 8100}}$$

$\gamma 1 = 0.0567$

yc = 270.0 mm

(EI)eff = 1.19 $\times 10^{13}$
Efficency = 0.13

Deflection = 21.75 **mm** SPAN/ 372

Strength

DL+0.4LL k1=0.94	
Mmax =	37.86kNm
Vmax =	28.39 kN
Ku = 2/3 Ks	γ **1 =** 0.0432
	γ **2 =** 1.0000
	a1 = 191.3
	a2 = 65.7
	yc = 255.7
	(EI)eff = 1.19×10^{13}
Timber k1=0.94	
ft,axial	+6.31 MPa
ft,bending	±8.04 MPa
Ft,axial	13.54 MPa
Ft,bending	27.92 MPa
Combined	0.75 < 1.00
fs	1.51 MPa
Fs	3.55 MPa
Ratio	0.42
Concrete	
fc,normal	-0.79 MPa
fc,bending	±4.80 MPa
Fc,tension	2.72 MPa
Fc,compression	11.52 MPa
Combined	0.49 < 1.00

If tension in concrete exceeds capacity reinforcement will contribute to capacity.

Shear connector

ØNj = Ø k1 k13 k14 k16 k17 Qlat

connector	M16	CS
Angle to grain	90	Deg
Spacing	200	mm
Embedment	100	mm
diameter	15.55	mm

Joint Group	JD4	
Qlat	18200	N

phi	0.80
k1	0.77
k13	1.00
k14	1.00
k16	1.20
k17	1.00

1.35DL – k1 0.77	
End fastener	
N* =	6.27
ØNj	13.45
Ratio	0.47 ok