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Better Acoustically Performing Structural Connections

Grant Emms et al.

Project LR0454

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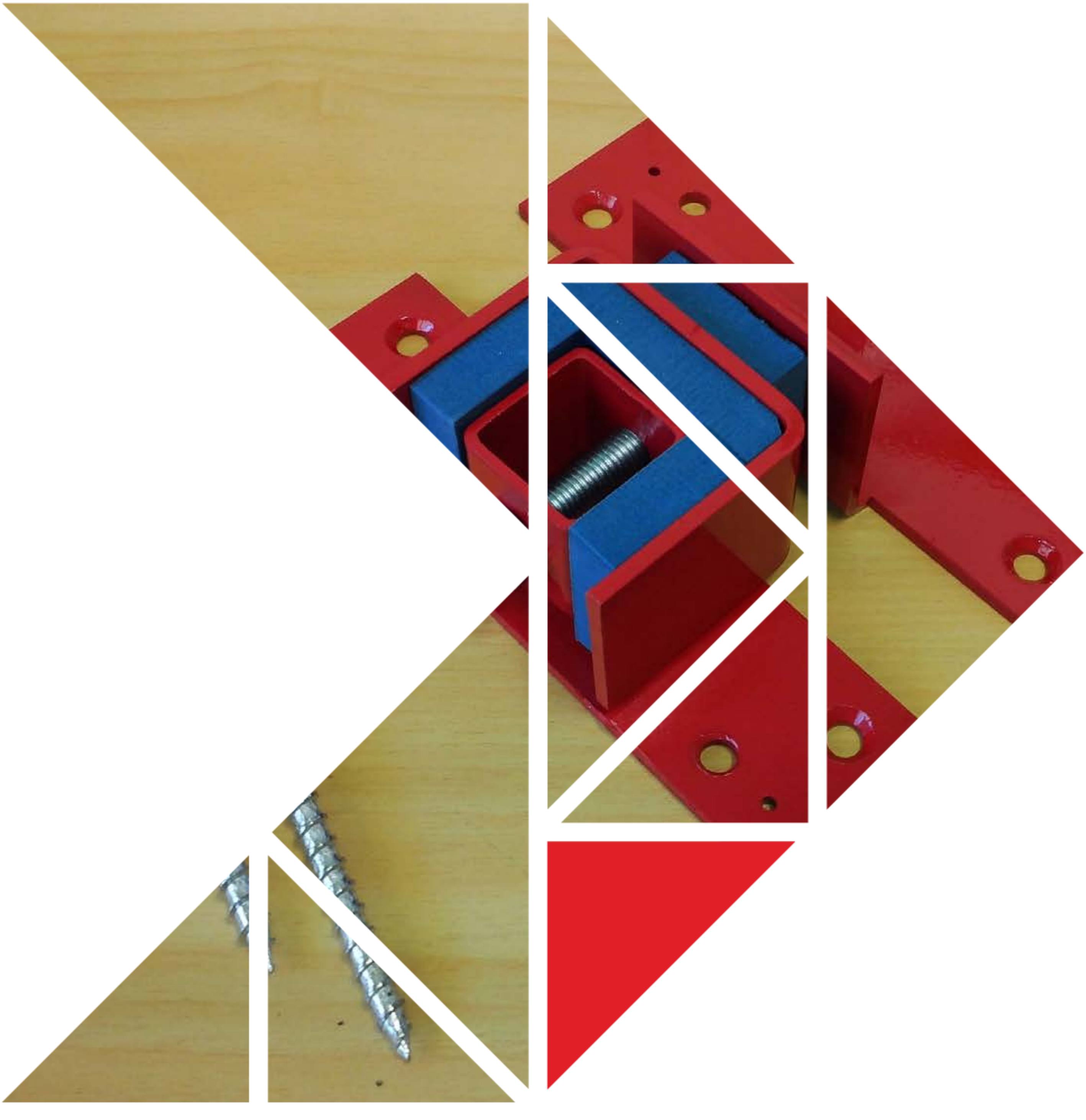

1222 Moonshine Rd,
RD1, Porirua 5381
Private Bag 50 908
Porirua 5240
New Zealand

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Better Acoustically Performing Structural Connections (LR0454)

2014/15 Building Research Levy Investment Programme

Final Report

Grant Emms, Doug Gaunt, Andrea Stocchero, Warwick Banks, George Dodd,
Keith Ballagh, Daniel Scheibmair, Hyuck Chung, Prof Brian Mace, In Ling Ng

REPORT INFORMATION SHEET

REPORT TITLE	BETTER ACOUSTICALLY PERFORMING STRUCTURAL CONNECTIONS (LR0454) – FINAL REPORT
AUTHORS	GRANT EMMS, DOUG GAUNT, ANDREA STOCCHERO, WARWICK BANKS, GEORGE DODD, KEITH BALLAGH, DANIEL SCHEIBMAIR, HYUCK CHUNG, PROF BRIAN MACE, IN LING NG
DATE	MARCH 2015

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EXECUTIVE SUMMARY

Report Title: Better Acoustically Performing Structural Connections (LR0454) – ***Final Report***

Authors: Grant Emms, Doug Gaunt, Andrea Stocchero, Warwick Banks, George Dodd, Keith Ballagh, Daniel Scheibmair, Hyuck Chung, Prof Brian Mace, In Ling Ng

Introduction

The easiest way to build light-framed party walls between units with good acoustic performance is to use a double-stud framing system. Ideally the double stud system consists of two frames that are not connected, and have a minimal separation between the frames (20mm). However, structural performance requirements limit design options (e.g. the size of windows), and for very tall (> 3 stories) and narrow buildings it becomes almost impossible to provide enough bracing to meet the seismic and wind-load structural performance requirements. Existing commercial connection systems are resilient enough to not overly affect acoustic performance, but do not provide enough structural connection for extreme seismic or wind loads. Currently, if designers are forced to provide suitable structural connection between frames, they must design their own connection systems, which may not be properly tested, either structurally or acoustically.

A structural connection system which provides the needed structural connection between light timber-framed multi-residential units to transfer seismic and wind loads, without compromising on the acoustic performance was developed.

The new structural connection system will make available more design options for designers, enabling taller light-framed systems to be built with fewer design compromises. This will also help ensure that buildings remain serviceable after extreme seismic events.

Work done

- Structural and acoustic requirements for the connectors were determined.
- A desktop search was conducted among existing structural connection systems that are acoustically isolating. The search provided different connecting systems that can be considered for the development of a new acoustically protected connection system.
- Preliminary design concepts were developed.
- Design and prototype build of two designs, an across-plate design and a through-joist design.
- Structural and vibration transfer testing of the two designs was performed.
- A final across-plate connector, which is fixed on to the bottom plates and into the edge joists was designed and built.
- Structural, laboratory-based testing of the final across-plate connector design was performed on individual connectors at Scion.
- Full-scale acoustic testing of the final across-plate connector was performed on a wall in the Auckland University acoustic chambers.

Key Results

- A load transferring connection system was developed which spans across the bottom plates of a double stud inter-tenancy wall, and is screwed through the bottom plate into the edge joists.
- Average measured force transfer at the Serviceability Limit State (SLS – assumed to be at 2mm displacement) was 500N in shear, and axial tension and compression.
- Average measured force transfer at the Ultimate Limit State (ULS – assumed to be 10mm displacement) was 3300N in shear, 2100N in axial tension and 2800N in axial compression. (Figure 3, Figure 4)
- The full-scale laboratory acoustic performance of the across-plate connector design was tested on a standard inter-tenancy double-stud wall with 2 layers of 13mm GIB

Fyreline lining each side (STC=63dB, Rw=62dB). For a connector fixed every 600mm along the wall, and adjusted to normal operation (i.e. first stage of coupling stiffness giving less contact to the foam) there was no effect on the acoustic transmission loss of the wall (with and without the connectors).
- When the across-plate connectors were compressed to provide full contact of the front foam pads to simulate possible creep of wall, the acoustic transmission loss performance reduction of the STC and Rw rating was 1dB (STC=62dB, Rw=61dB), which is a not noticeable change. (Figure 2)
- Based on the cost of fabricating the prototypes, the cost of each connector to make is approximately $100. Mass production would drop this cost.

Knowledge Dissemination Steps

- Publish results in New Zealand Acoustics, the journal of the Acoustical Society of New Zealand.
- Publish results in the journal of the Timber Design Society of New Zealand.
- Work with MiTek and Pryda to develop commercial versions.

Figure 1. Across-plate connector design prototype screwed on to bottom plates, through flooring and into the edge joist.

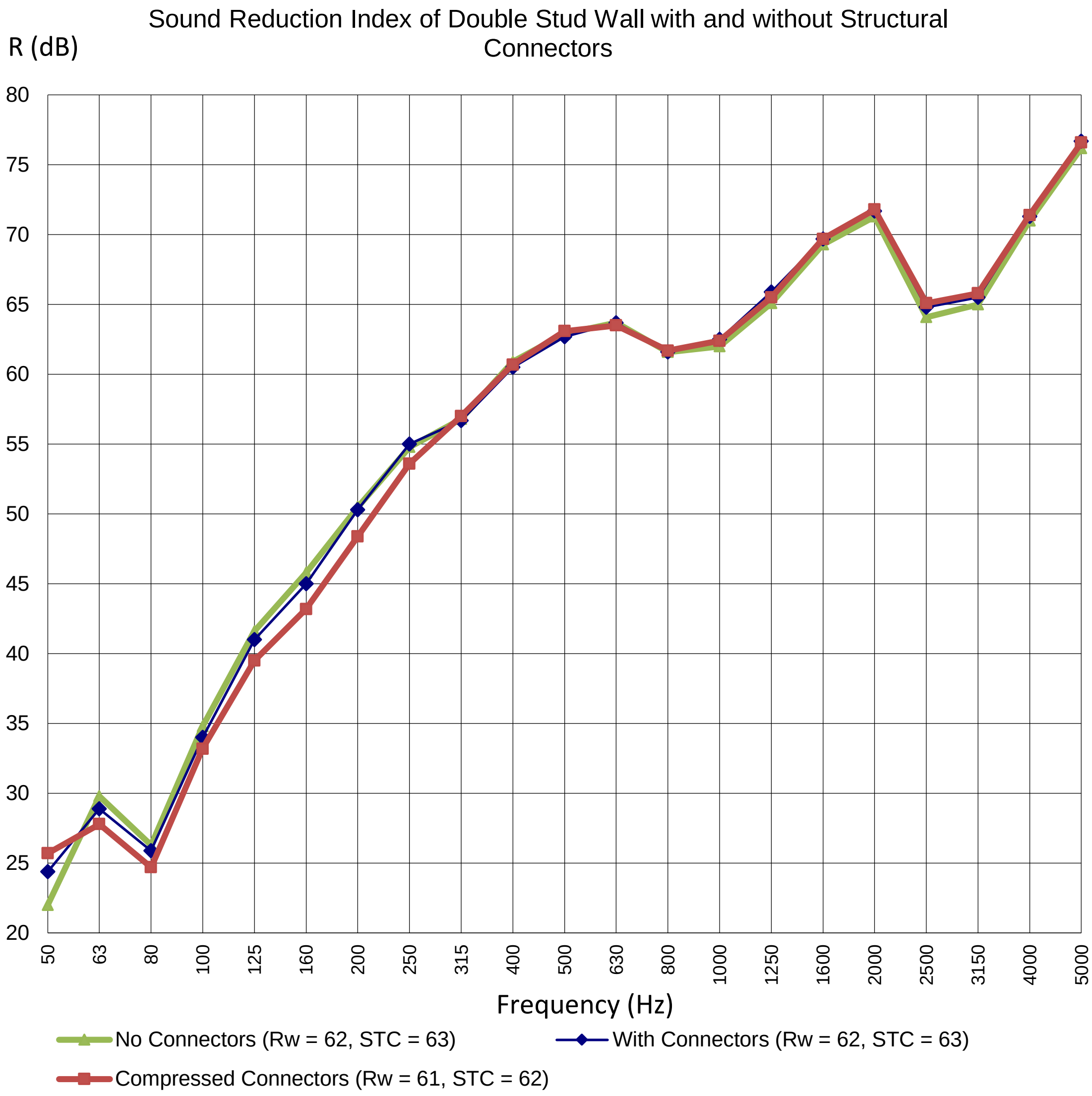

Figure 2. Sound Reduction index of a double-stud wall with and without the across-plate connectors every stud spacing.

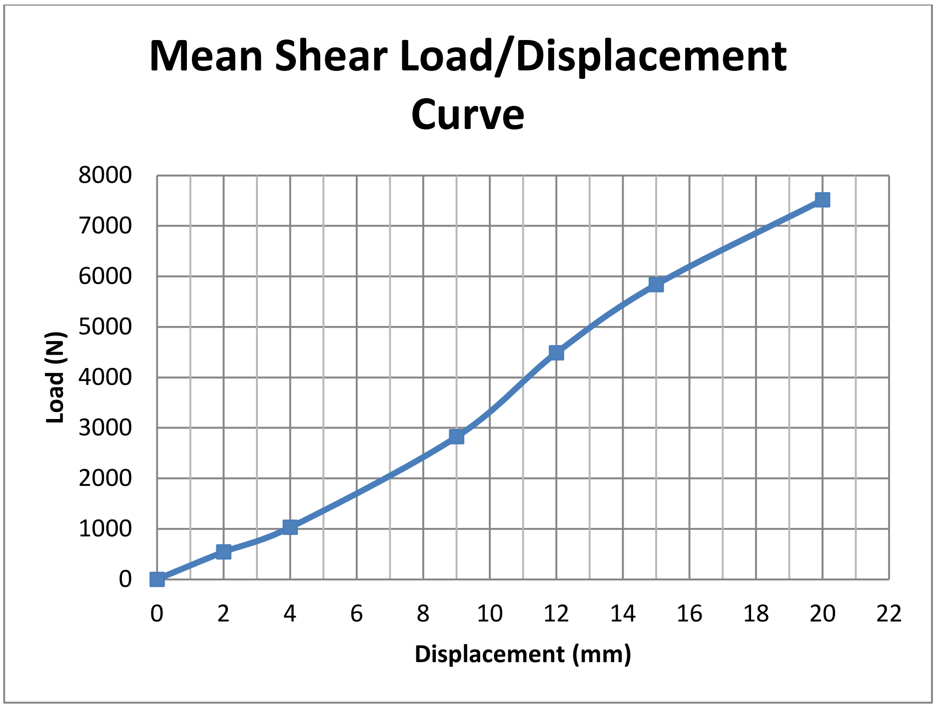

Figure 3. Averaged Load deflection curve for shear cyclic test of three specimens. Average of shear response in both directions.

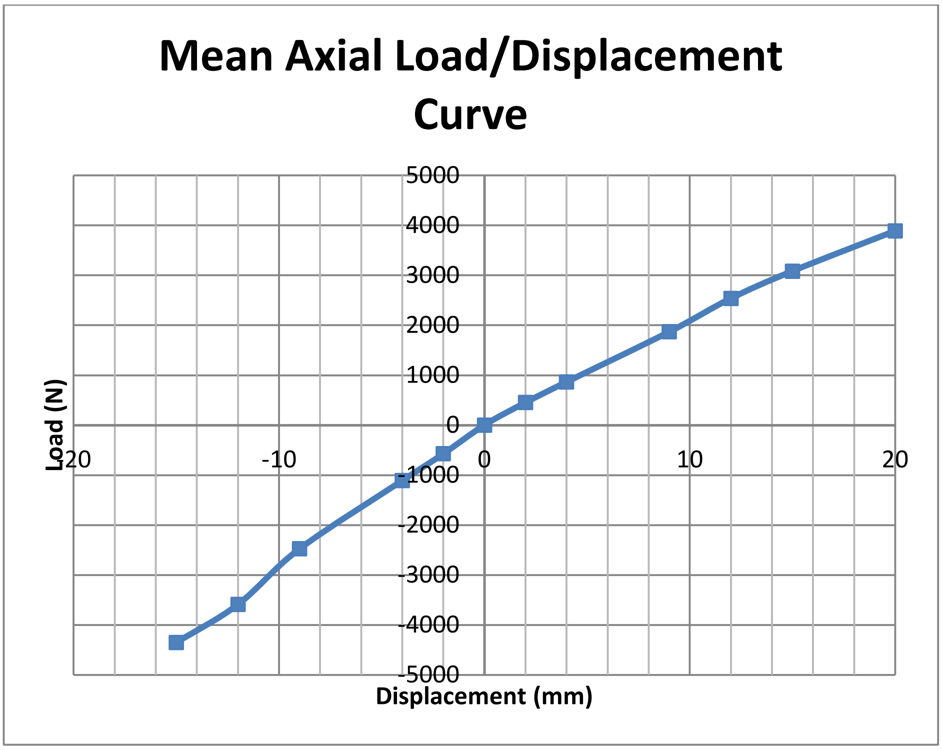

Figure 4. Averaged load deflection curve for axial cyclic loading test of three specimens. Negative displacement and load corresponds to compression and positive displacement corresponds to tension.

BETTER ACOUSTICALLY PERFORMING STRUCTURAL CONNECTIONS (LR0454)
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March 2015

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Introduction

Research project background

This research addresses the theme of building better cities and communities by supporting the construction of high quality medium and high density housing in the urban environment.

A structural connection system which provides the needed structural connection between light-framed timber multi-residential units to transfer seismic and wind loads, without compromising on the acoustic performance was developed.

The new structural connection system will make available more design options for designers, enabling taller light-framed systems to be built with fewer design compromises. This will also help ensure that buildings remain serviceable after extreme seismic events, something that the finance and insurance industries currently encourage.

This research is particularly focused on terraced housing, where significant growth can be expected in New Zealand’s main urban centres, particularly for timber framed buildings.

The easiest way to build light-framed party walls with good acoustic performance is to use a double-stud framing system. Ideally the double stud system consists of two frames that are not connected, and have a minimal separation between the frames (20mm). However, structural performance requirements limit design options (e.g. the size of windows), and for very tall (> 4 stories) and narrow buildings it becomes almost impossible to provide enough bracing to meet the seismic and wind-load structural performance requirements. Existing commercial connection systems are resilient enough to not overly affect acoustic performance, but do not provide enough structural connection for extreme seismic or wind loads. Currently, if designers need to provide suitable structural connection between frames, they must design their own connection systems, which are not properly tested, either structurally or acoustically.

This research aimed to develop connection systems which maintain a high degree of disconnection between frames in normal situations to achieve a high degree of acoustic isolation. However, when strong loads (seismic or wind) are present, the connection systems will engage to provide a high degree of connection in order to transfer these strong loads, and then return to normal when the loads are no longer present. The performance of these systems was verified in laboratory tests.

Objectives

The objective of this research is to provide the design community with an inter-tenancy housing structural connection system which can achieve the structural and acoustic insulation performances required by end users and other stakeholders.

Outcomes

The outcome of this research will be the enabling of better and cheaper construction of multi-residential housing, particularly terraced housing, which have more certain structural performance under extreme seismic or wind load, whilst maintaining superior inter-tenancy sound insulation, and allowing greater design freedom.

Research method

The aim of this research is to develop inter-tenancy structural connectors which provide good structural connection when a building is under extreme external loads from seismic events or extreme wind events (see Figure 5). However, under normal conditions, when the building is not under extreme external loads, the connectors will provide little structural connection, giving excellent acoustic isolation between units. To focus the project we examined inter-tenancy connections in terraced housing.

This research project has arisen from research carried out previously with BRANZ (Report SR 208), where the use of a continuous diaphragm to provide the necessary structural connection was assess, and has been realised that there might be other ways of connecting buildings together when there are extreme loads.

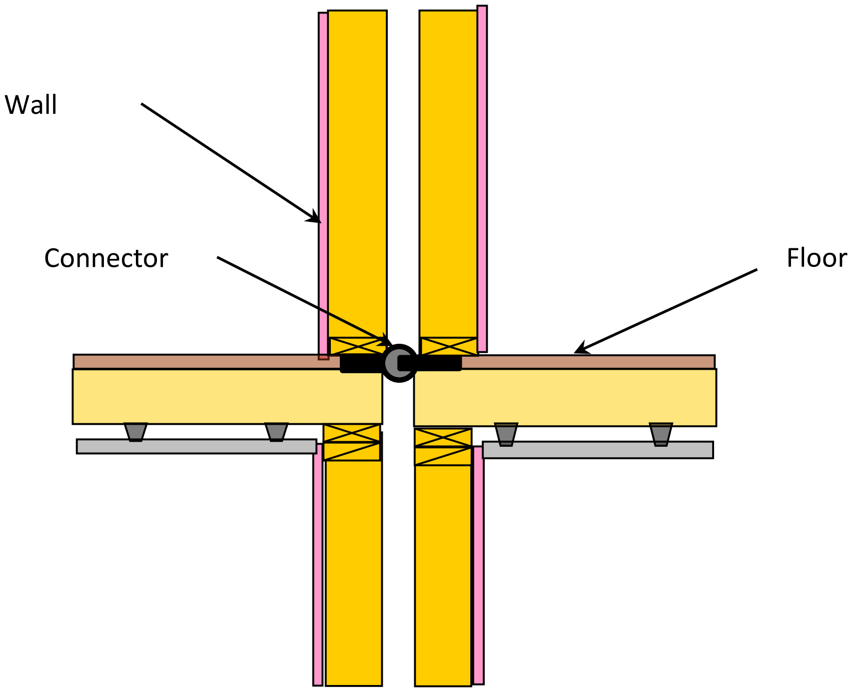


Figure 5. Cross section of inter-tenancy double-stud wall showing potential structural connector location to transfer loads across the floor diaphragm.

Overview of this Report

This report is presented as a main body presenting the final connector design, construction and testing, which is supplemented by appendices collating the preliminary designs and test results.

The first section, **Design Requirements,** describes the expected structural and acoustic requirements which set the design direction.
The second Section, **Connector Design,** describes the final design of the connector, also describing the design logic.
The third section, **Connector Fabrication**, gives instruction to fabricate the connectors.
The fourth section, **Acoustic Measurements**, presents the full-scale wall acoustic transmission loss measurements of the final design.
The fifth section, **Structural Measurements**, presents the structural measurements of final design.
The final section, **Conclusion**, concludes by summarising the key findings.

Design Requirements

Structural Requirements

Seismic design overview

When two buildings are located close to each other, they may hit each other during strong earthquake shaking and cause damage. This effect is called *pounding*. Theoretically, if the two buildings have the same characteristics, then under the same earthquake motions they should move together, in phase, without hitting, in the same way that windscreen wipers on a car move together.(MacRae, Clifton, & Megget, August 2011)
However, due to different foundation conditions, different structural types and differing building heights, buildings seldom have the same characteristics.
Pounding may be guaranteed to not occur during a design level earthquake, if the distance between the buildings is greater than the sum of the maximum displacements of each building alone without considering pounding. The computed maximum displacement of each building is affected by assumptions, about the structural stiffnesses and the soil conditions, which affect the periods of the structure.(MacRae et al., August 2011)
In the common terraced houses design and construction practice the distance between building units does not guarantee avoiding pounding. Furthermore, as many terraced houses do not have any bracing walls at all towards one end of the building mitigating the structural displacement occurring under seismic and wind stress.
Structural connection systems provide the needed structural connection between light-framed timber multi-residential units to transfer lateral loads.

Connection requirements

The connections need to work at both Serviceability Limit States (SLS) and at Ultimate Limit States (ULS). The designs are predominantly governed by seismic loads at elastic load levels ($\mu = 1.0$).
The loads and displacements at SLS are generally around 20% of those at ULS. For example when considering 5kN load at ULS, SLS will be 0.2x5= 1kN.
The loading directions will be in the plane of the floor, both tension/compression and shear. Some nominal capacity for vertical loading is also to be expected.
Displacements at ULS are expected to be a maximum of 10mm in shear and axial tension/compression. Therefore, displacements at SLS are expected to be 2mm. These displacements are expected, nominal values; actual values will depend on the specific building design.
The connectors also need to transfer load into the structural components of the floor (viz. floor diaphragm and joists) and so the area near the connector may need extra fasteners for high load transfers.

In order to get an indication of the approximate load transfer required for a connector we calculated the load transfer required in a basic terraced house design. We considered the case of a terraced house in Wellington (a worst case seismic risk scenario for New Zealand) with 12m long inter-tenancy walls. On the top floor, which is the floor requiring the most load transfer, we need 80kN of load transfer (compression/tension and shear) for that particular floor.
This expected worst-case scenario equates to 6.7kN per metre of wall, or 4kN per 600mm stud spacing. Similarly, SLS will be 1.3 kN per metre of wall, or 800N per 600mm stud spacing.

These numbers are just a severe-case starting guide for us, in practice, the number of connectors required per floor will be driven on how large the floor plans are, the height of the floor above ground level and the location within the country.

Once designers have the structural capacity of the connector (for a specified ULS displacement) then they will determine how many they need for their specific project.

Acoustic Requirements

High performance acoustic requirements for a structural connector

To achieve high performance results, we want any structural connector to not significantly influence the acoustic energy transmitted into the neighbouring partition through a double stud wall. To define this limit we assume that the effect of such connectors is such that they reduce the sound insulation performance of the wall by less than 1dB – an insignificant change in acoustic performance which would not be noticeable by people.

In general, due to the double skin and low mass nature of a timber frame wall system, the acoustic performance is poorest in the low-frequency region. In the low-frequency region, where the sound wavelengths are much greater than the distance between the linings, the acoustic performance of a double stud wall system is governed by the air stiffness of the air gap between the layers (as well as the mass of the linings).
The sound reduction index at low frequencies (above the mass-air-mass resonance, and below cavity resonances) is approximately given by (Fahy, 1985)

$$R = 20\log_{10}\left(\frac{2\rho s'/k}{(2\pi f)^2 m_1 m_2}\right)$$

where s' is the stiffness per unit area of the air (and other resilient connections) between the wall leaves with surface masses m_1 and m_2 for frequency f and wavenumber k, and where ρ is the air density.
At higher frequencies the sound transmission becomes more complicated due to in-cavity resonances, the sound absorbing infill, and the effect of bending waves in the linings. We will ignore higher frequencies, since a lightweight double-leaf wall system is usually more highly performing at higher frequencies, and so the single figure ratings such as STC and R_w tend to be controlled more by its low-frequency performance.

We can see from the above equation for the sound reduction *R* that if we want a performance reduction of less than 1dB, the wall ties should only increase the stiffness of the coupling between the wall linings by 12% from that of air alone.

The stiffness of air is given by

$$s'_{air} = \rho c^2/d$$

Where d is the separation between the wall linings, c is the speed of sound in air and ρ is the air density.

Let us assume our double-stud wall has a separation of 200mm between the linings (2x90mm studs plus a 20mm gap). The stiffness of the air per unit area s'_{air} is therefore 722500 N/m/m^2, and hence the stiffness per unit area of any additional connections must be less than 87,000 N/m/m^2. For a storey height of 2.8m this equates to a stiffness of 240,000 N/m per metre of wall.

If, in a severe-case scenario requiring high load transfer, we used a tie every 0.6m stud spacing along the floor for a wall height of 2.8m, we would find that each tie would need to have less than 146 kN/m of stiffness.

Minimal acoustic performance criteria

If we regard a less than 1dB performance reduction as being not noticeable, what could we regard as a noticeable, but acceptable performance reduction?

Let us assume our double stud wall is made of 2 layers of 13mm Fire-rated plasterboard with a separation of 200mm between the linings (2x90mm studs plus a 25mm gap) and an infill of 90mm thick fibreglass. Feeding this wall description into the acoustic transmission loss prediction software Insul 7 (www.insul.co.nz) gives that wall a single figure rating of Rw=65 and STC=66. Mostly determined by the low frequency performance (250Hz and below).
The current New Zealand building code, section G6, requires an STC rating of 55 (with a 5dB on-site allowance). The future version of G6 is likely to require an Rw of 55.
We can, therefore, compromise our double-stud wall performance by up to 10dB. This corresponds to an increase in wall leaf couple stiffness to about 3 times that of air alone. Or, that our wall tie system adds stiffness equal to 2 times that of the air. So the wall ties could have an average per unit wall stiffness of 1440 kN/m/m^2.

If, in a severe-case scenario, we used a tie every 600mm along the floor for a wall height of 2.8m, we would find that each tie would need to have less than 2,400 kN/m of stiffness. Such ties could potentially be made using standard rubbers or urethane foam as the resilient material. If they had a maximum displacement of 2mm for SLS and were linear they could provide 4.8kN of structural connection. This is well beyond the expected severe-case structural requirements of 800N per 600mm spacing.

Intermediate acoustic performance criteria

If we start from structural requirements of 1.3kN of load transfer per metre of wall for SLS and a maximum displacement of 2mm, we see that this would require a linear stiffness of 667 kN/m. per metre of wall.
This is a 55% increase in wall cavity stiffness due to air alone, giving a 4dB reduction in performance at low frequencies.

Non-linear Stiffness Coupling

In the above considerations we have assumed that the stiffness of the resilient material is linear (doubling the force doubles the displacement of the material). In order to have the best of both worlds, we can have a nonlinear resilience which start soft (under normal conditions - say within 1mm movement), and becomes much stiffer when displaced more (under extreme wind or seismic loads).
One way of implementing this non-linearity is to have a small area contact area for the first 1mm of displacement and a larger contact area for greater displacements.

Acoustic Design Requirements Summary

In summary, it is possible to provide effective structural connection without overly compromising the acoustic isolation provided by a double stud wall. A non-linear resilience would allow for best normal in-service acoustic performance whilst providing structural coupling in extreme events.

Connector Design

Preliminary Connector Designs

Two initial preliminary designs for connector systems were developed:

- **Through-joist connector**: A large load transfer design which can be connected through the edge joists (only a few units needed per apartment),
- **Across-plate connector**: A lower load transfer design which can be mounted on the bottom plates and spans across the double stud gap (the lesser load transfer would require that more units be used).

These designs were fabricated and tested. The design and results of this testing are presented in Appendix C.

Final Connector Design

After analysis of the test results of the preliminary design, the through-joist connector design was discontinued based on poor shear force transfer results, and feedback that a through-joist connector might be difficult to install and check.

A final version of the across-plate connector was further developed and copies fabricated:

Appendix D provides fabrication instructions.

Across-plate Connector

The final design of the connection system is screwed to bottom plates and spans the double stud gap. The SLS design aim was approximately 800N load transfer with 2mm displacement both tension/compression and in shear. The ULS design aim was approximately 4kN with 10mm displacement both tension/compression and in shear.

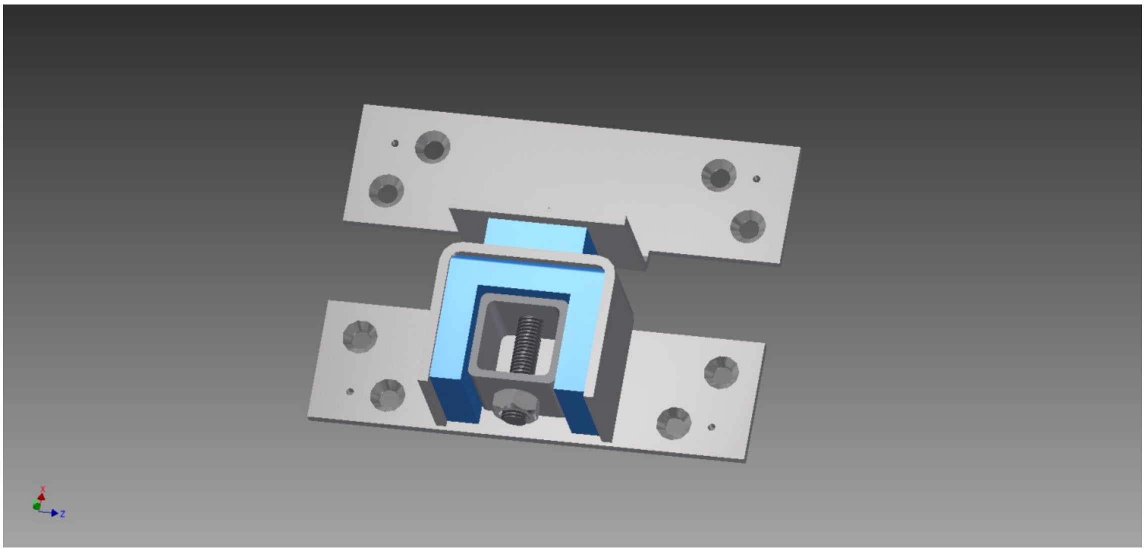


Figure 6. Across-plate connector design, complete perspective view.

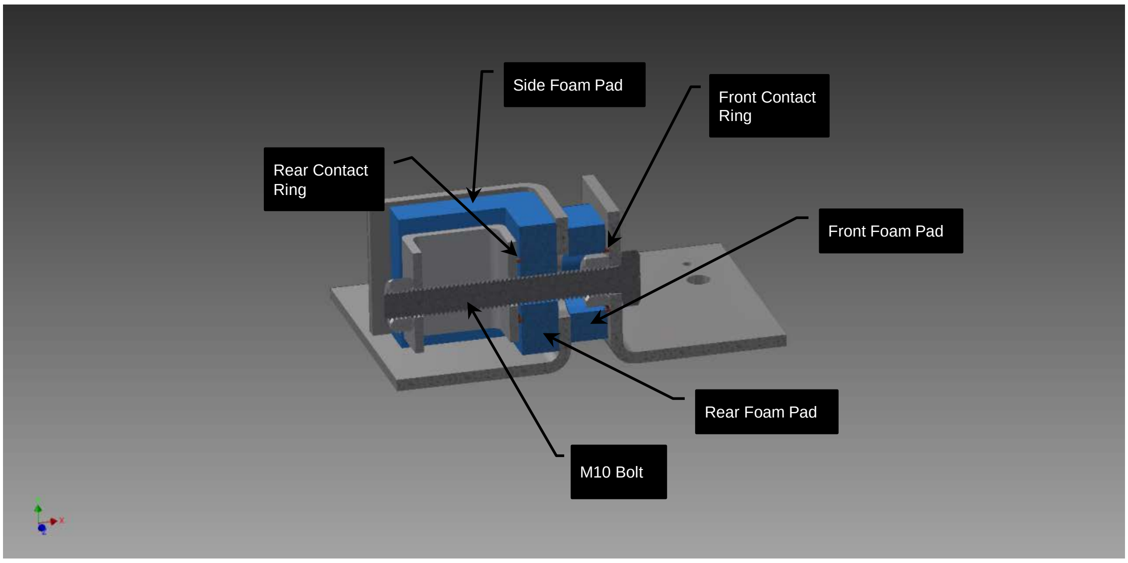


Figure 7. Across-plate connector design in cross section view.

Figure 8. Across-plate connector design prototype as screwed on to bottom plates. Two pairs of screw holes are provided each side, but only one pair is expected to be used to penetrate middle of edge joists (and only these were counter sunk).

Design Logic and Description

The system is designed to be screwed to the bottom plates and joists of a double-stud wall system, spanning across the gap between the two bottom plates. The connection is via an M10 bolt with a rigid connection one side and resilient connection the other side. The brackets are made from 4mm folded steel

Axial resilient connection is via blue resilient (front and rear) foam pads (12.5mm Sylomer SR850 urethane foam – similar to rubber with Shore A value of 75 - static E is 7.2MPa, and dynamic E is 11.1MPa) acting through 1mm thick and 2mm deep contact rings (denoted Front and Rear in Figure 7), providing the first, high-resilience stage of a two-stage resilience, with the steel brackets providing the second stage. The M10 bolt needs to be tensioned to depress the 2mm thick rings into the foam by 1mm.

A further 2mm of axial displacement (1mm on ring and 1mm into bracket face) is calculated to give a load transfer of 850N.

Shear resilient connection (horizontal) is via the side foam pads and bracket flanges. To transfer shear forces and isolate the connecting M10 threaded bolt we rigidly connect one end of the bolt to the bracket and resiliently isolate the other end through the blue urethane foam pads.
2mm of horizontal shear displacement is calculated give a load transfer of 800N.

Screw connectors on each bracket were 2 of Rothoblas HBS8160 HBS SCREWS 160mm long. This should achieve the required ULS load of 4kN in shear and tension and compression, as well as transferring forces into the joist.

The design of the preliminary version of the across-plate connector (see Appendix C) was updated to:

- Simplify fold pattern of 4mm steel.
- Increase main hole to 22mm diameter
- Increase bracket height to allow more tolerance to height mis-match between resilient and non-resilient brackets (up to 6mm now)
- Use 35x35 square hollow section (3mm wall thickness) steel cut to 35mm long with 10mm hole drilled through it, in place of u-shaped section. This enables easier access of nut to screw on to bolt (which is 80mm long now). Also is a readily available steel tube section.
- Add some small 3mm diameter holes for locating the connector with small nails prior to screw fixing.
- Include two pairs of counter sunk holes for wood screws on each bracket. Only one pair is expected to be used at a time.

Connector Fabrication and Installation

In this section we describe how to fabricate, assemble and install the final design of the across-plate connector.

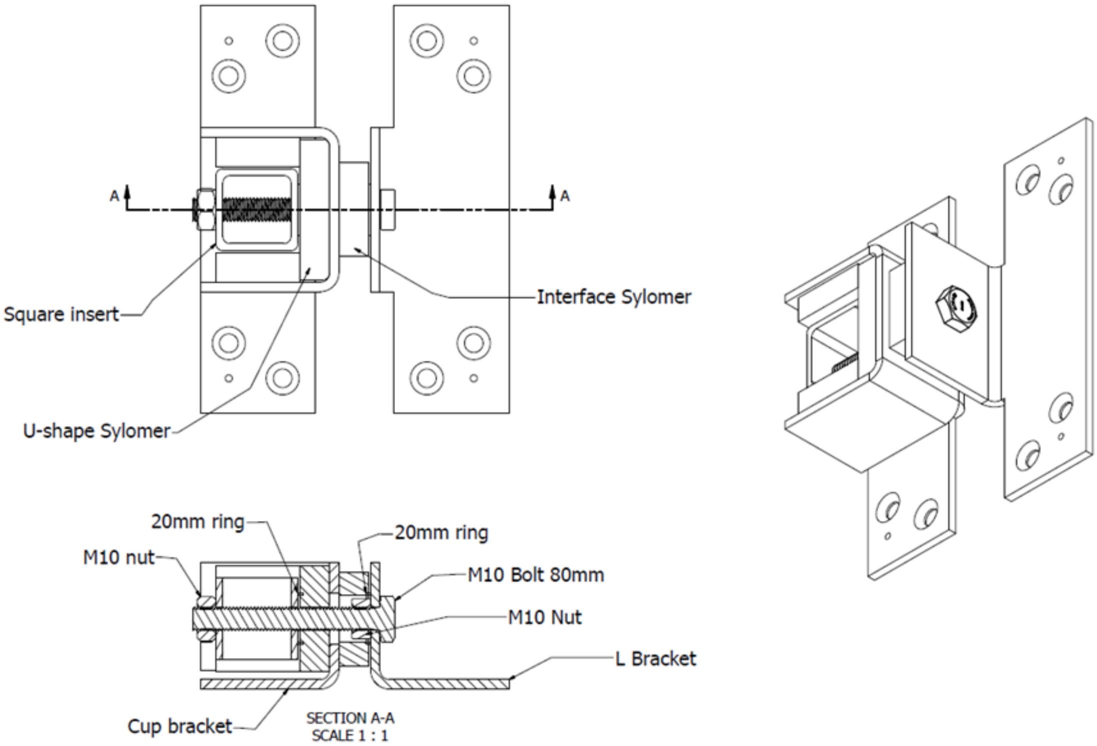


Figure 9. Assembled across-plate connector

Parts List

1 x ‘Cup Bracket’ – 4mm mild steel (Yield strength grade 300MPa).
1 x ‘L Bracket’ – 4mm mild steel (Yield strength grade 300MPa).
1 x ‘Square Insert’ – 35x35x3mm SHS 35mm long, mild steel
1 x Bolt M10 80mm, zinc-plated, property class 8.8
2 x Nut M10, zinc-plated, property class 8.
2 x 20mm (ID) Ring (2mm deep, 1mm wall thickness), any metal e.g. Al.
1 x U-shape Sylomer, Sylomer urethane foam SR 850, sections glued to form u-shape using suitable glue (e.g. rubber cement glue).
1 x Interface Sylomer, Sylomer urethane foam SR 850.

Detail drawings of the parts are shown in Appendix D.

Part Fabrication Notes

The ‘Cup Bracket’ and the ‘L Bracket’ are made from cut and folded 4mm mild steel (Yield strength grade 300MPa). Drawings in Appendix D show the fold patterns. Screw holes are counter sunk to accept Rothoblaas HBS counter sunk type wood screws.

The Square Insert is a 35mm long piece cut from 35x35x3mm Square Hollow Section mild steel tube with 10mm holes drilled though it. The steel parts can be painted with corrosion preventative paint.

The 20mm (ID) Rings were cut from aluminium tube with OD 22m and ID 20mm and depth 2mm. Any metal could be used.

The Sylomer urethane foam parts were water jet cut from 12.5mm Sylomer SR850 Sheet (Made by Getzner, New Zealand agents are Pyrotek New Zealand). The U-shape Sylomer part is made by gluing 3 pieces together using suitable contact adhesive or epoxy glue (e.g. Ados F2). Potentially this part could be moulded as one part. Note that the front corners of the U-shape Sylomer assembly will need to be chamfered by 3mm to allow a better fit into the Cup Bracket.

Figure 10. Steel parts (from left to right), L bracket, Cup Bracket, Square insert.

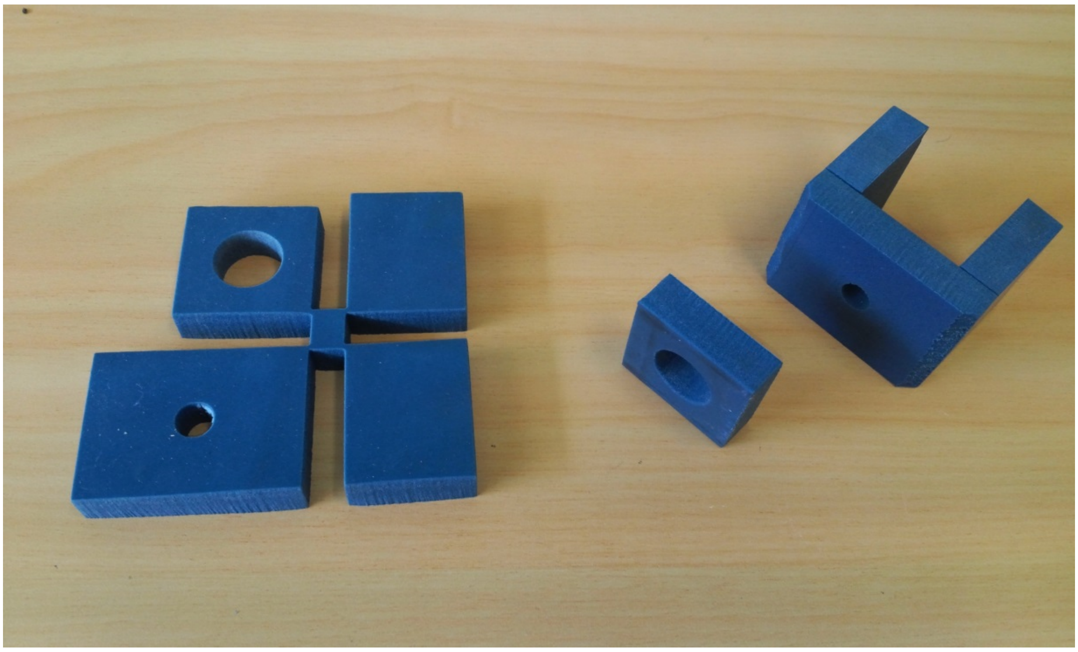


Figure 11. Sylomer foam pads. The four-pad set after water jet cutting (left), the final assembly of the U-shape Sylomer (right). Note the chamfer on the front corners of the U-shape Sylomer assembly to allow a better fit into the Cup Bracket.

Assembly of Connector

1. The M10 bolt is inserted through the 10mm hole in the L-bracket, a M10 nut is screwed on to the bolt and tightened on to the L-bracket.
2. One 20mm ring is slipped over the nut to press against the L-bracket.
3. The interface Sylomer pad is slipped over the bolt, and over the nut to press against the ring.
4. The Cup Bracket is inserted over the bolt so that the front face is against the interface Sylomer pad.
5. The U-shape sylomer pad is slipped over the bolt thread to rest inside the cup region of the cup bracket.
6. The second 20mm ring is slid over the end of the bolt to rest against the U-shape sylomer.
7. The Square Insert is then slid over the end of the bolt to rest against the 20mm ring.
8. The final M10 nut is screwed on to the end of the bolt. Loctite or a locking nut is recommended.
9. The final M10 nut is tightened against the Square Insert until the sylomers pads are pushed into the 20mm rings and there is a 0.5mm – 1mm gap between the Interface Sylomer pad and the L-bracket and a 0.5mm – 1mm gap between the U-shape Sylomer pad and the Square Insert. This degree of tightening ensures that only the first stage (area) of stiffness is engaged, reducing the vibration coupling. Over tightening the final M10 nut so that the full area of the Interface and U-shape Sylomer pads is pressed against the brackets on both sides may result in more vibration transfer and reduced acoustic performance.

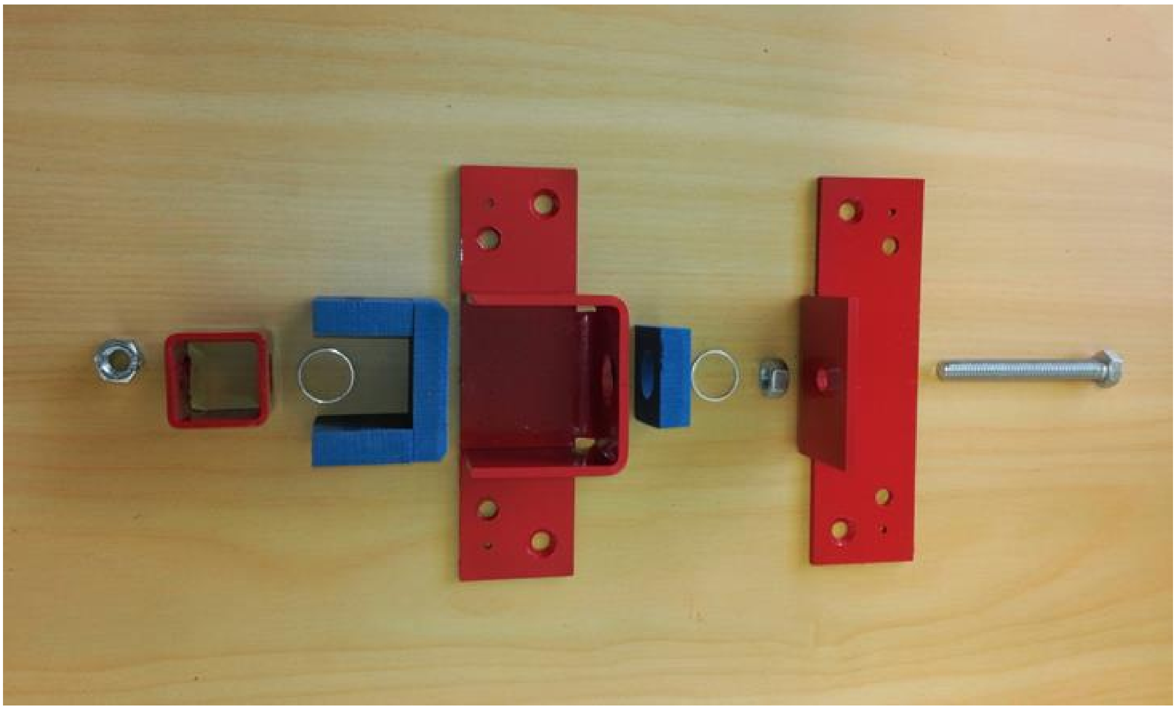


Figure 12. Exploded view of the parts of the connector, showing the assembly order.

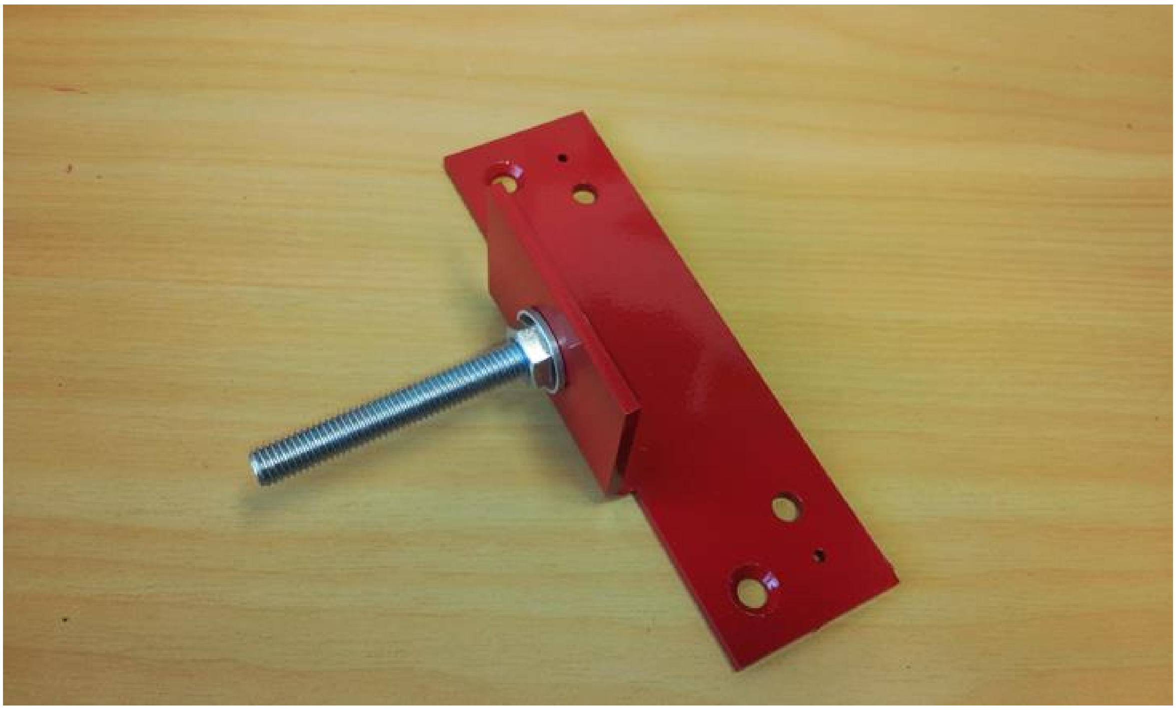


Figure 13. Assembly, step 2 completed.

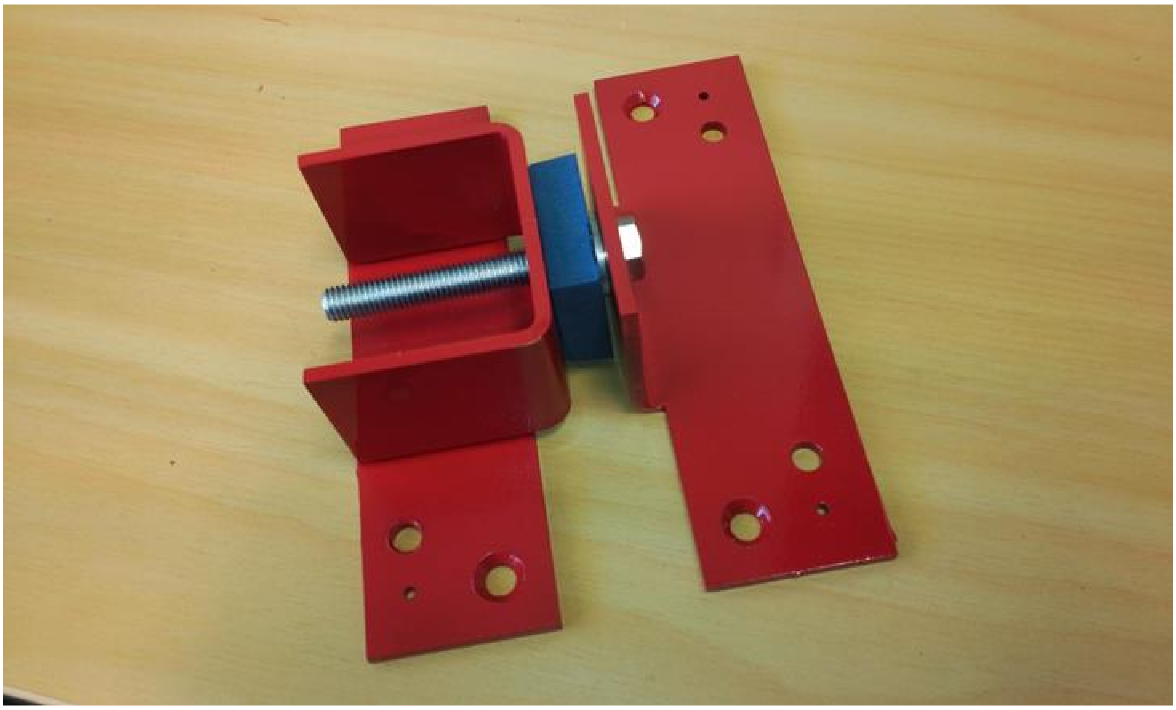


Figure 14. Assembly, step 4 completed.

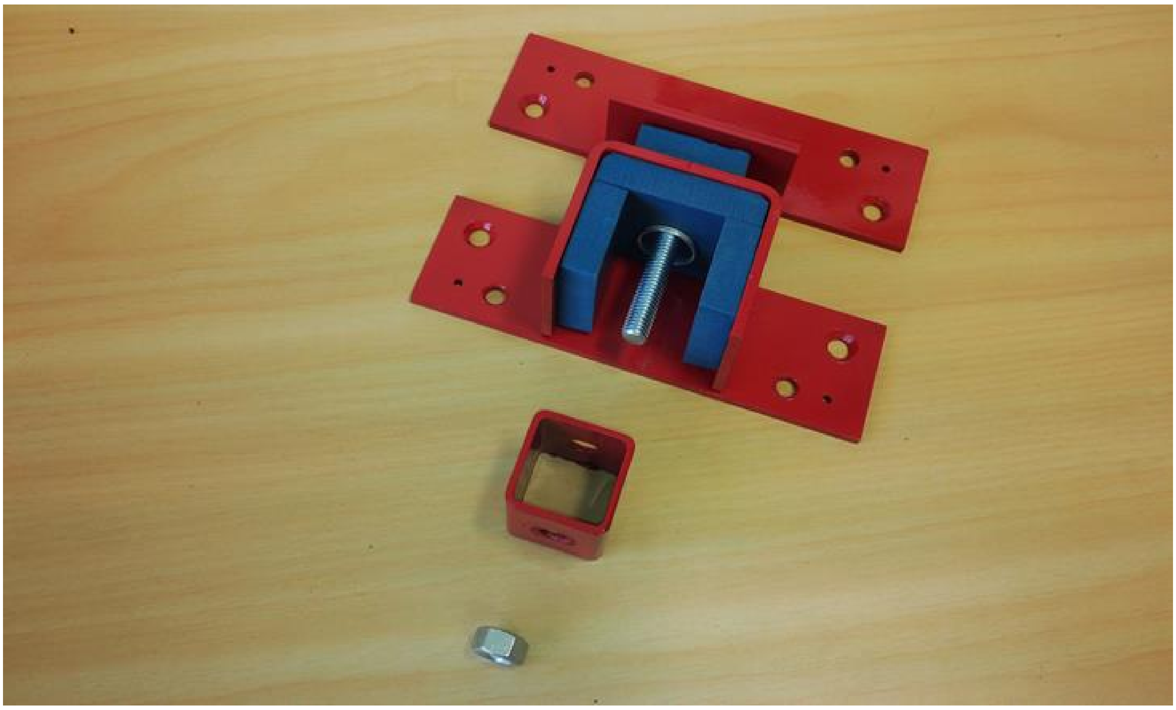


Figure 15. Assembly, step 7 completed.

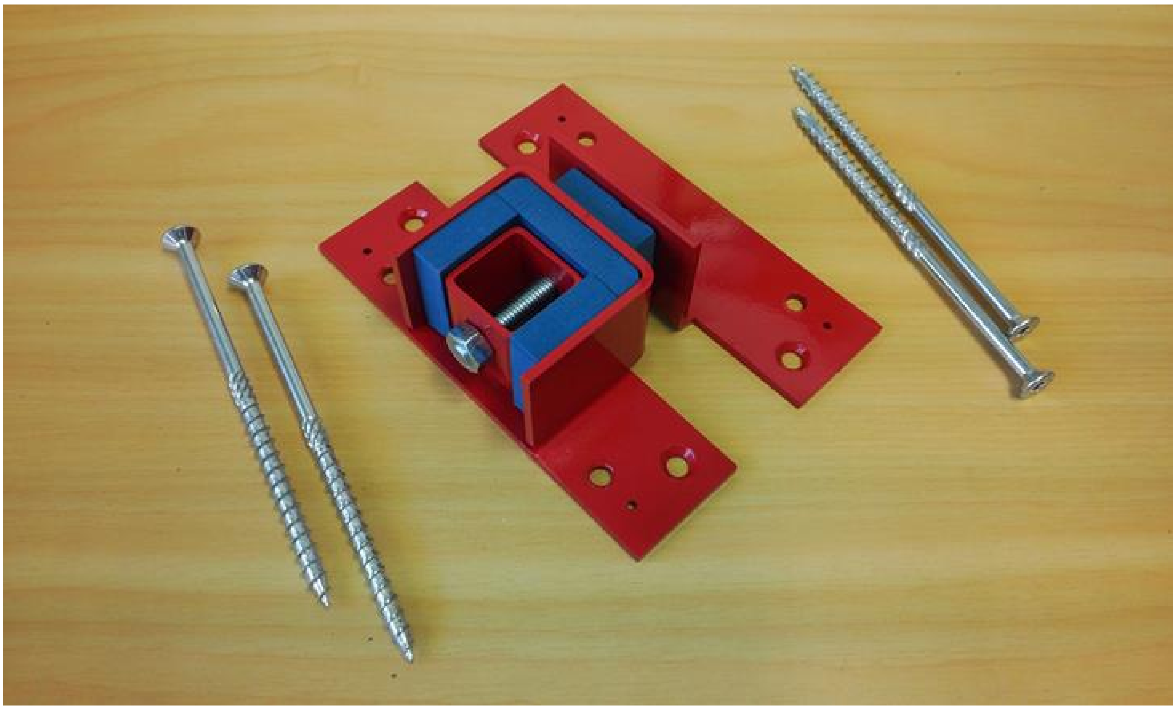


Figure 16. Assembly completed.

Installation

In our trials the acroos-plate connector was mounted on to the bottom plates, spanning the gap between the walls and screwed into the bottom plates, flooring and edge joists using two Rothoblaas HBS 160mm 8g screws (Figure 17 and Figure 18). This enables load transfer from the connector to the floor.

When installing the brackets it is better to not distort the positioning of the connector during screwing in of the wood screws. Positioning the brackets by hand first and drilling pilot holes is a recommended installation step. Small nail holes are provided in the design to enable the bracket to be tacked into position to help with the installation.

The design of the brackets can handle a height differential between the two bottom plates of up to 5mm. Shimming with a plate covering the full area of under a bracket (L-bracket or Cup Bracket) is recommended for any greater height differential.

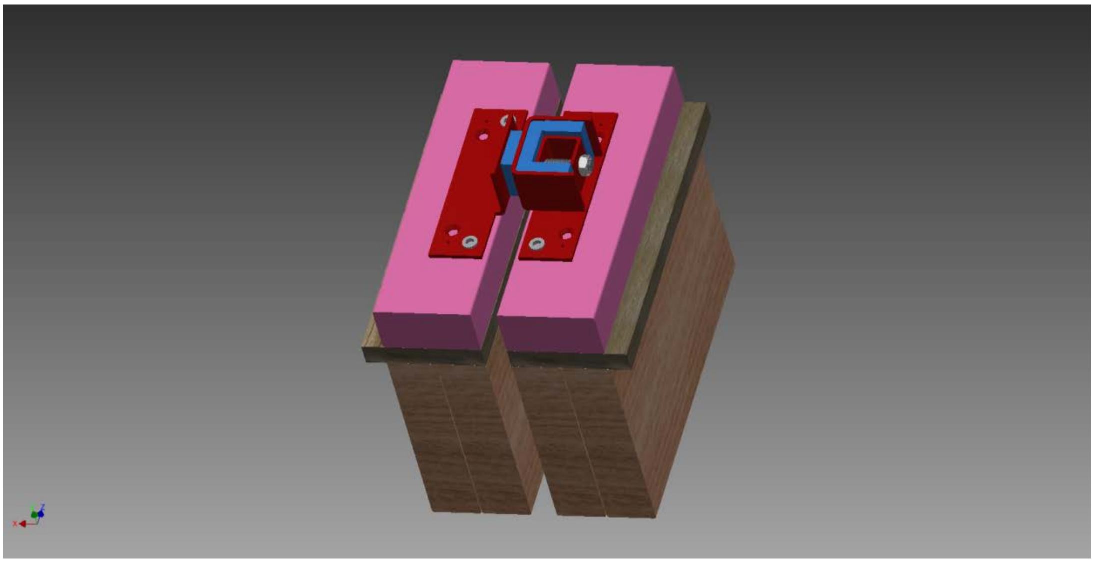


Figure 17. Perspective drawing of the across-plate connector showing installation on to bottom plate and screwed into edge joists.

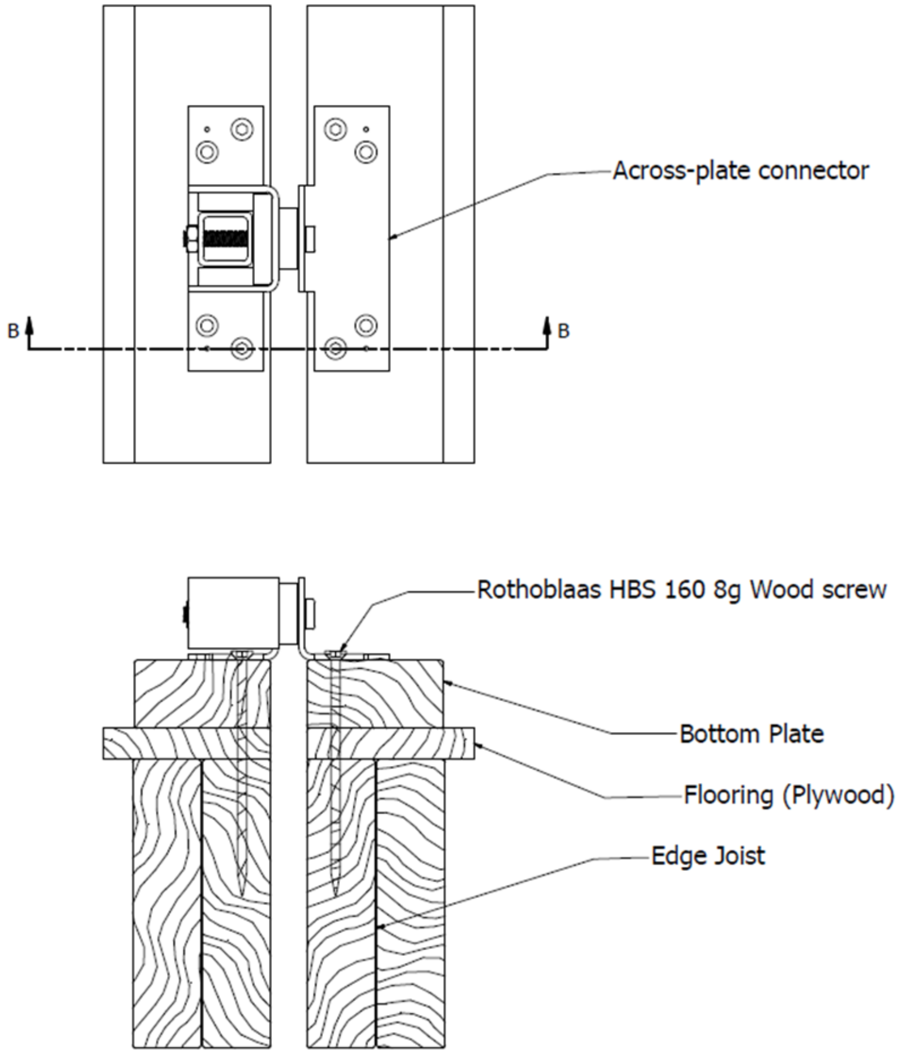


Figure 18. Diagram of across-plate connector installed on to bottom plate, showing installation position of 160mm wood screws, screwed into edge joists.

Acoustic Measurements

Full-scale acoustic transmission loss wall measurements were performed at Auckland University's Acoustic Test Laboratories.

Measurement setup

Wall construction

The test wall was a Double-stud wall consisting of 2 layers of 13mm Fyreline, a frame gap of 25mm, and Autex Green stuff R1.8 95mm polyester infill (See Gib GBT(L)A90c wall system from GIB Noise Control Brochure, March 2006). The GIB manual stated that Rw= 62, and STC =63 for this wall.

Bottoms plates of frames were each set on two joists 240mm deep.

The wall had sections cut from the plasterboard near the bottom plates to allow access for the structural/acoustic connectors on the bottom plate.

The top plates, edge studs were screwed into the chamber collar. The joists were placed on the bottom part of the collar and only screwed at the ends of the joists into the side collar to allow vibration movement in the joists to simulate a real wall.

The edges of the wall were sealed with acoustic sealant.

The joists were covered with plasterboard boxing to screen any sound coming through the acoustically weaker joists. This plasterboard boxing was not fixed to the wall, only sealed to the wall with resilient acoustic sealant.

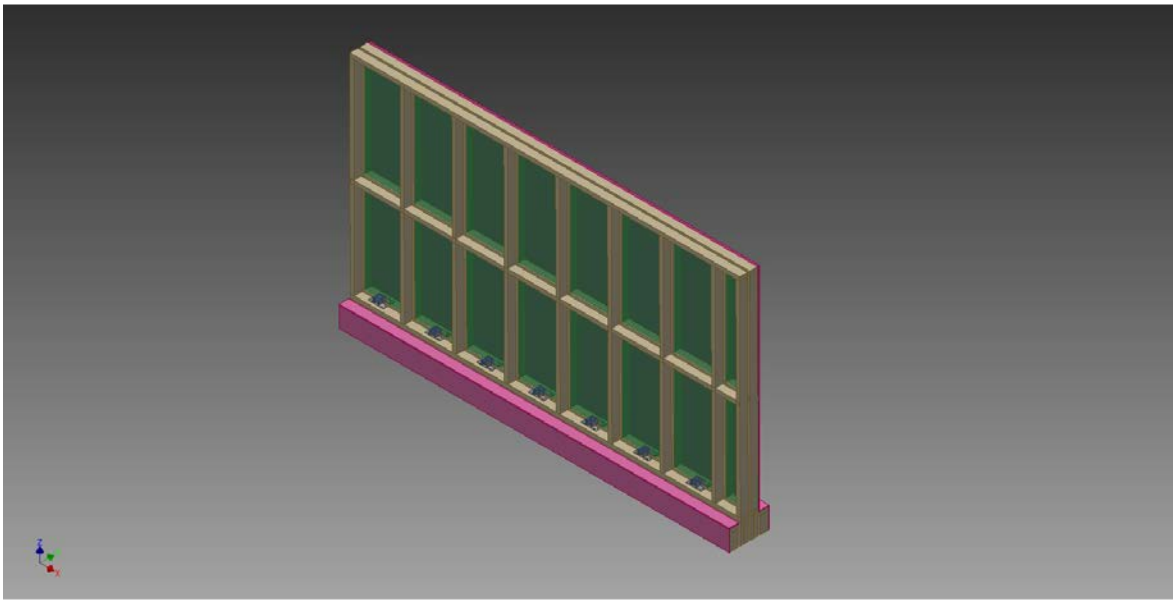


Figure 19. Cut away (front plasterboard removed) of the double stud test wall showing the positioning of the connectors.

Figure 20. Cross section of the double stud acoustic test wall with and without the connectors.

Test Chambers

The test space consists of two sound-isolated concrete chambers with a 4.5m long x 2.6m wide aperture in which to build a wall. The chambers are separated by a gap bridged by a wooden collar with a 5mm gap in the collar separating the two chambers.

The wall frames spanned the collar gap between the chambers (A & B) such that the gap between the test wall line up with the gap between the chamber collars. The chambers conform to ISO and ASTM requirements for such acoustic chambers.

Figure 21. The acoustic chambers without our test wall. Clearly showing the aperture with its wooden collar.

Figure 22. Our test wall built into the acoustic chambers' test aperture.

Connector Attachment

Our Connector Systems under test were screwed to the bottom plate and into the joists using Rothoblass HBS 8x160mm screws. 7 connectors were used – one every full-sized stud spacing.

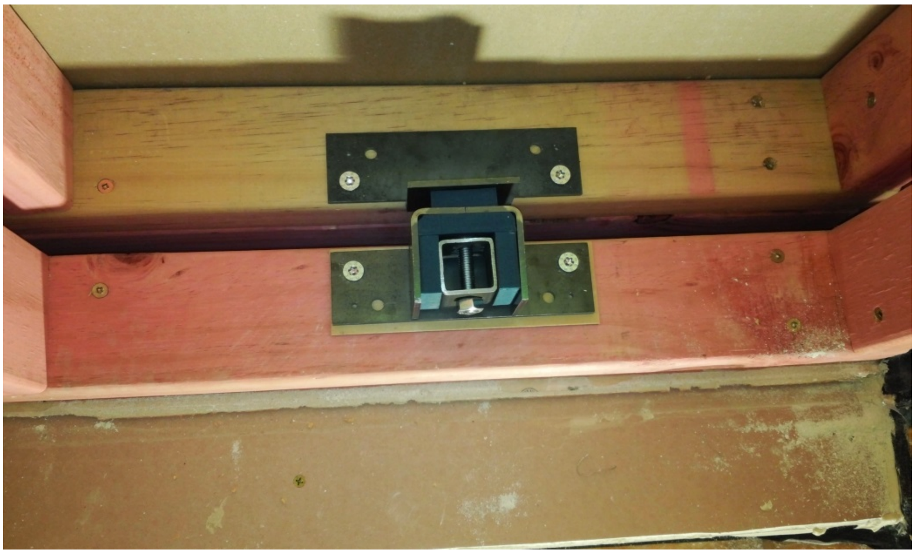


Figure 23. A connector fixed to the bottom plate of the test wall. The 160mm screws penetrate into the joists.

Acoustic Transmission Loss Measurements

The acoustic performance of the connectors was measured in the Auckland University Acoustics laboratory in accordance with ISO 10140-2. Essentially sound is produced in one chamber on one side of the test wall and the sound which is transmitted through the wall into the other chamber is measured. This produces values of the so-called transmission loss of the wall as a function of sound frequency. These transmission loss results are further processed to produce the ASTM standard STC rating and the ISO standard R_w rating.

Three measurements were made (Figure 24):

1. No connectors attached to get a baseline measurement of the wall. (Rw = 62dB, STC = 63 dB)
2. A connector every stud spacing (600mm) set in its normal, low-stiffness mode of operation. (Rw = 62dB, STC = 63 dB).
3. A connector every stud spacing (600mm) compressed to simulate movement of wood which may compress the connectors beyond 1mm into a stiffer region of operation, giving more vibration transfer. (Rw = 61dB, STC = 62 dB).

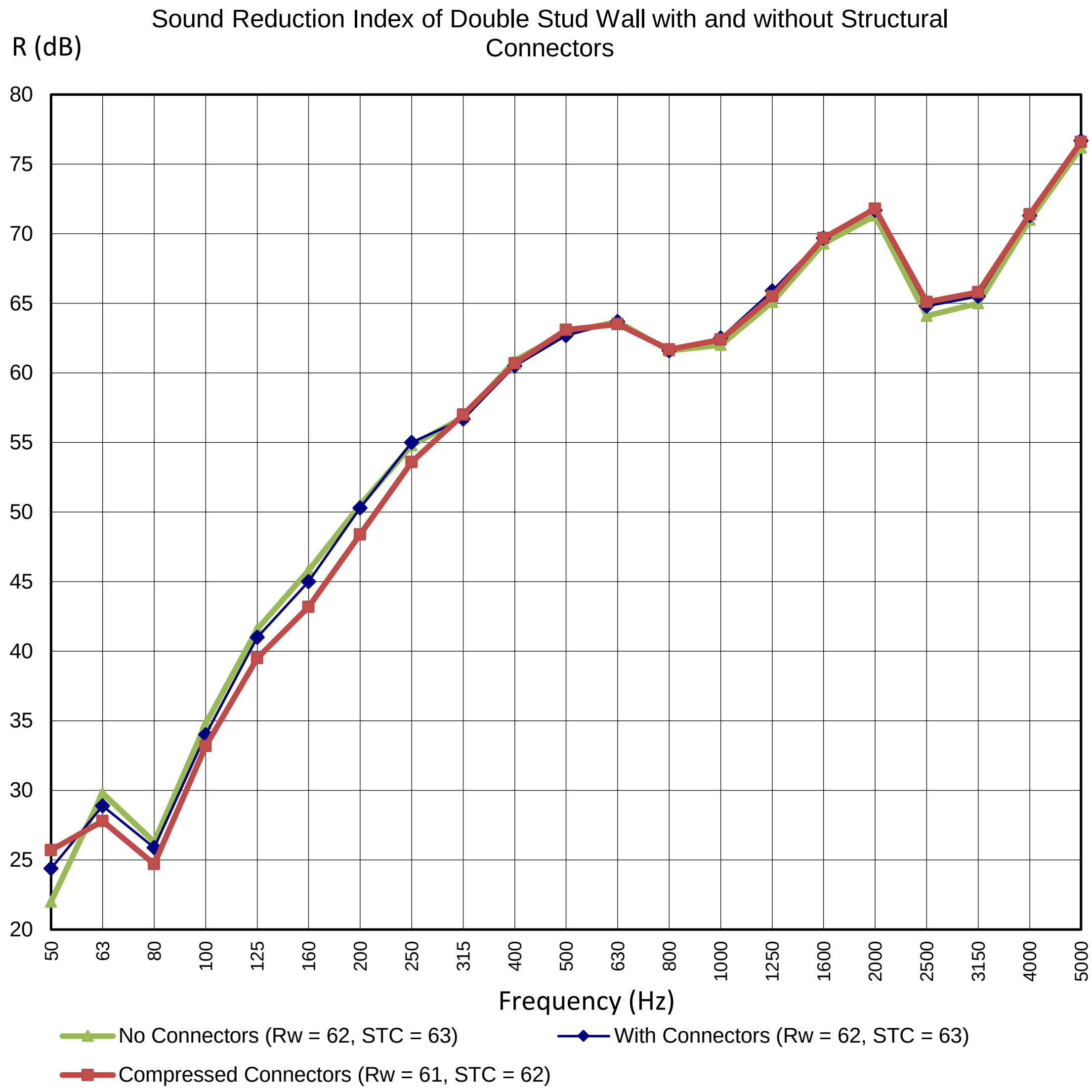


Figure 24. Sound Reduction index of a double-stud wall with and without the across-plate connectors every stud spacing.

Acoustic Measurement Comments

It can be seen from Figure 24 that the attachment of the connectors has very little effect on the wall, up to 2dB for the relatively stiff compressed state at frequencies below 315Hz. Above 315 Hz there is almost no significant vibration transfer.

Structural Measurements

The tests were conducted to simulate an earthquake sequences by adopting the "Earthquake test procedure" loading sequences proposed within the "BRANZ Evaluation Method No 1 (1999) for Structural Joints - Strength and Stiffness Evaluation".

Loads were applied to the four specimens to achieve the following increasing sequence of displacements: ±2mm, ±4mm, ±9mm, ±12mm, ±15mm, ±20mm. The displacement values were reached in cycles of 3 repetitions per displacement until the sequence of cycles end (±20mm reached 3 times) or depending on specimens' behaviour (unsustainable deformation).

Measurement Setup

The connections were fixed to an assembly of 90x45 mm framing bottom plate, 20 mm plywood and 2x 240x45 mm edge joist sections, as shown in Figures 14 and 15, simulating a double-stud wall with 20 mm cavity structure. Two Rothoblaas HBS8160 self -tapping screws have been used for this purpose. Timber used was rated SG8..

A Wiedemann Universal Testing Machine was used to apply the displacements to the specimens.
Displacements have been collected using a ±25mm Linear Variable Deflection Transducer (LVDT) and data logged directly from the test machine with 5 readings per second from the Data Logger.
The outputs from the Data Logger have been copied into Microsoft Excel to generate the Load Deflection Plots.

Tests were done for both, axial tension/compression as well as shear.

Figure 25. Across-plate connector shear load test.

Figure 26. Across-plate connector axial load test.

Results

Three specimens were tested in each test orientation of axial and shear. The maximum load results (first cycle) for each cycle limit (2,4,9,12,15,20mm) were averaged for all the measurements. The results of these measurements for shear and axial tension and compression are shown in Figure 27 and Figure 28 respectively.

Examples of cyclic loading test curves for a single specimen is shown in Figure 29 and Figure 31.

After the cyclic loading test, two specimens, one in shear and one in axial tension, were tested to maximum limits. The connectors themselves didn't fail, in both cases the timber failed. The load / displacement curves are shown in Figure 34 and Figure 36. The failure modes are shown in Figure 35 and Figure 37.

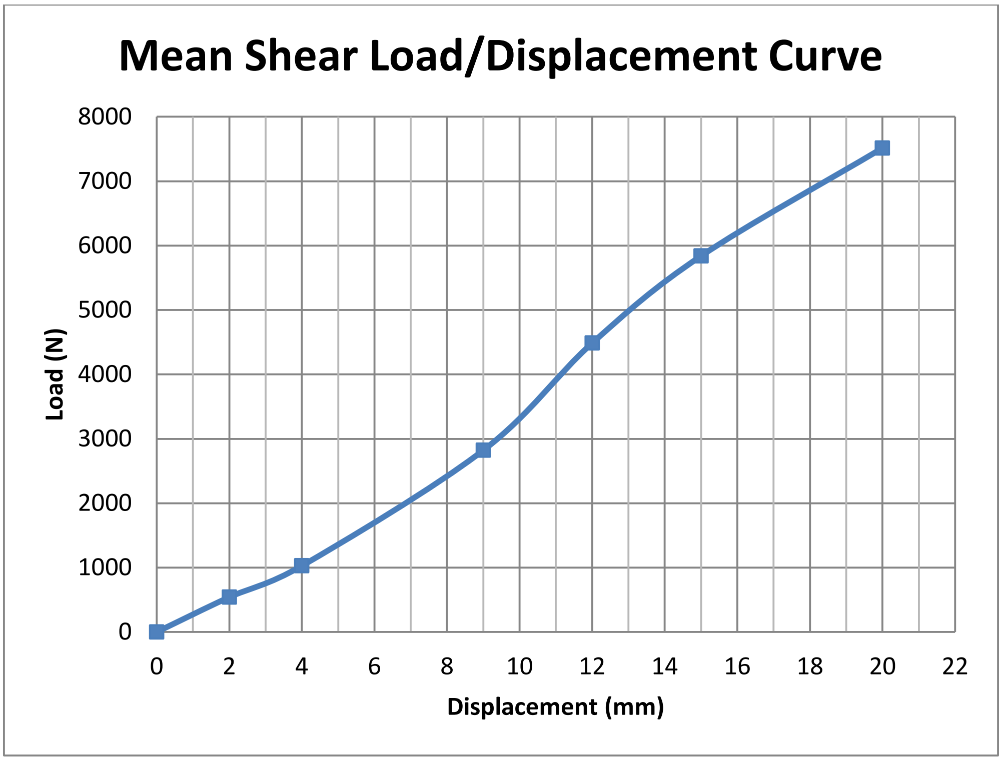


Figure 27. Averaged load **deflection curve for shear cyclic test of three specimens. This is the average of shear response in both directions.**

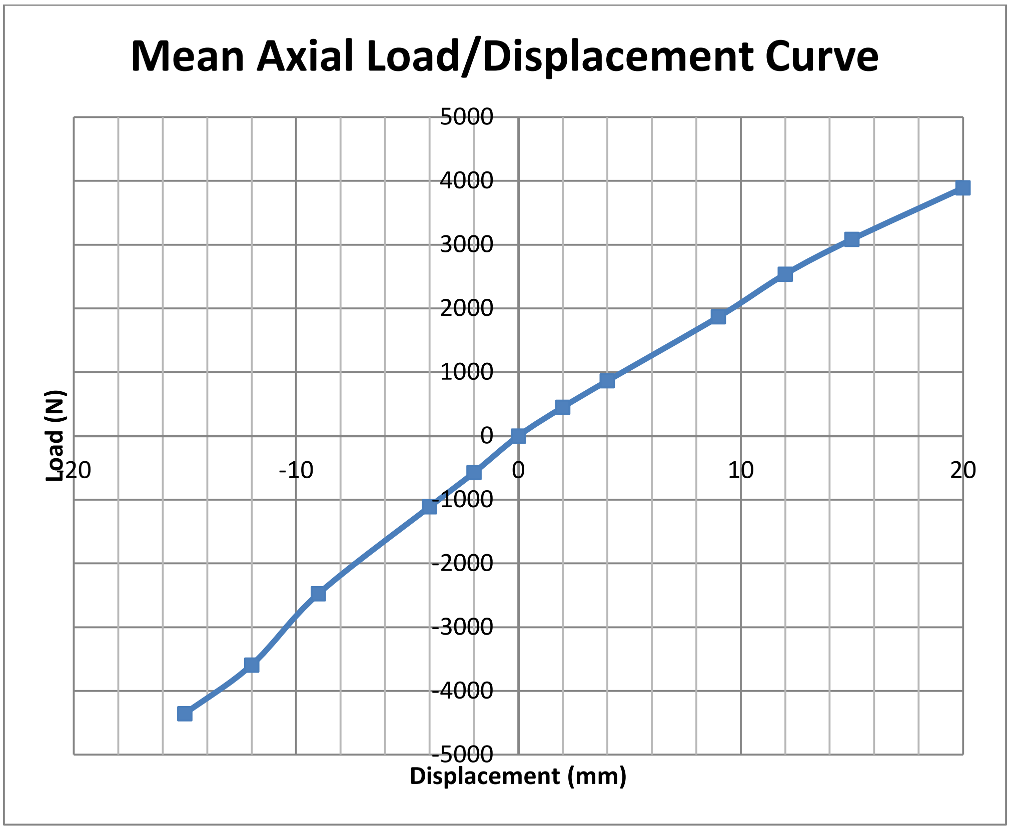


Figure 28. Averaged load deflection curve for axial cyclic loading test of three specimens. Negative displacement and load corresponds to compression and positive displacement corresponds to tension.

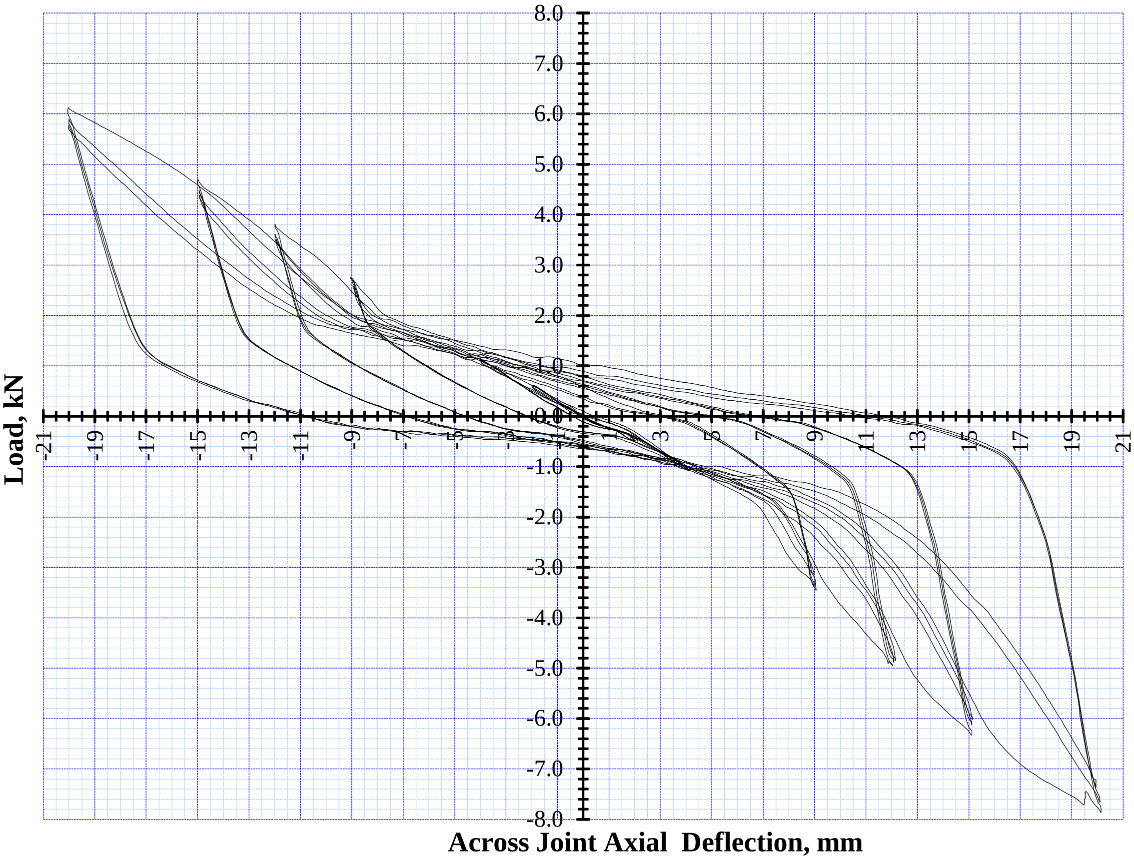


Figure 29. Load deflection curve for shear cyclic test of a single specimen

Figure 30. Shear cyclic test showing movement of SHS within bracket.

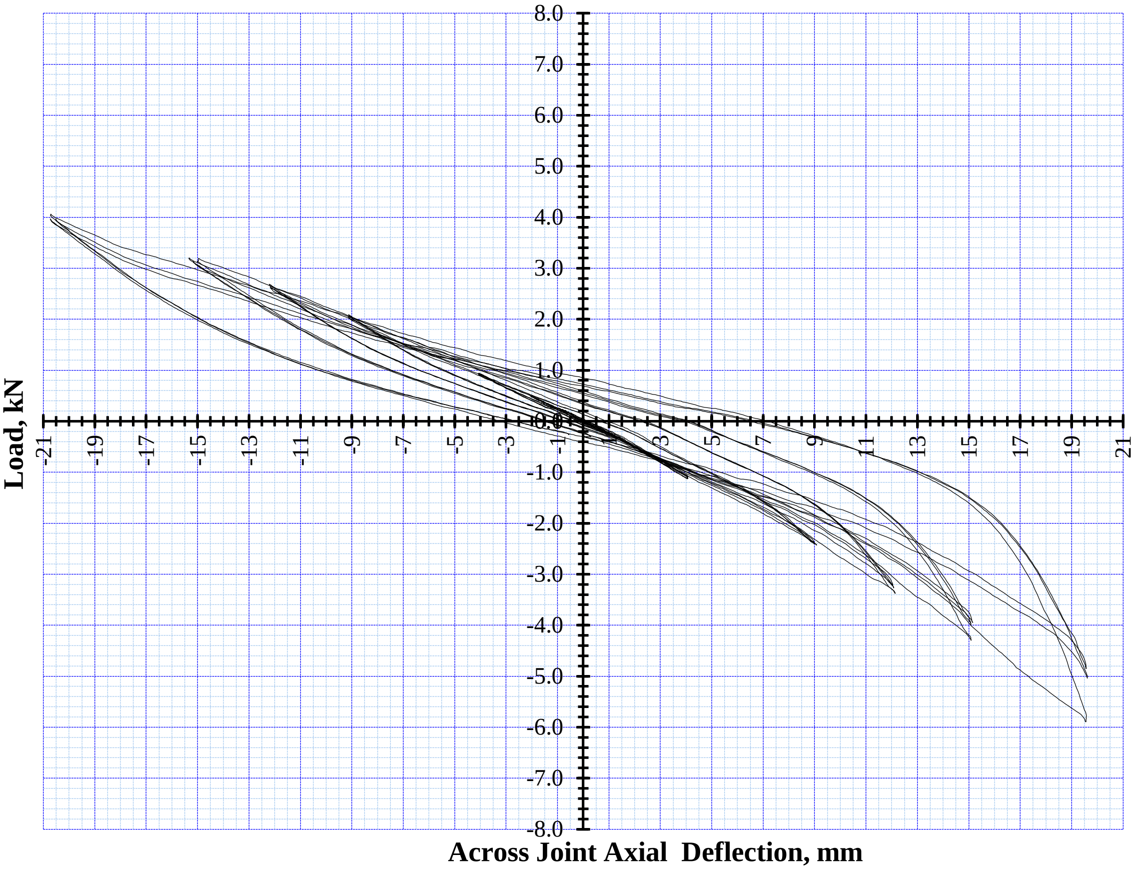


Figure 31. Load deflection curve for axial tension/compression cyclic test of a single specimen (positive deflection is compression)

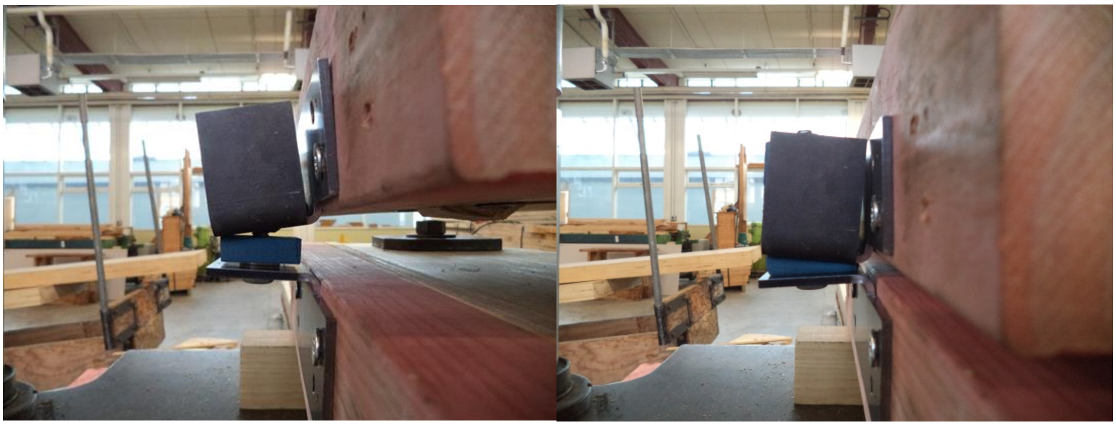


Figure 32. Axial cyclic loading test showing flexure of brackets at 9mm displacement. Note that the brackets are rotating at its attachment to the timber when in tension.

Figure 33. Axial cyclic loading test showing flexure of brackets at 15mm tension displacement. Note that the part of the brackets which are faced to the timber are flexing as well as rotating.

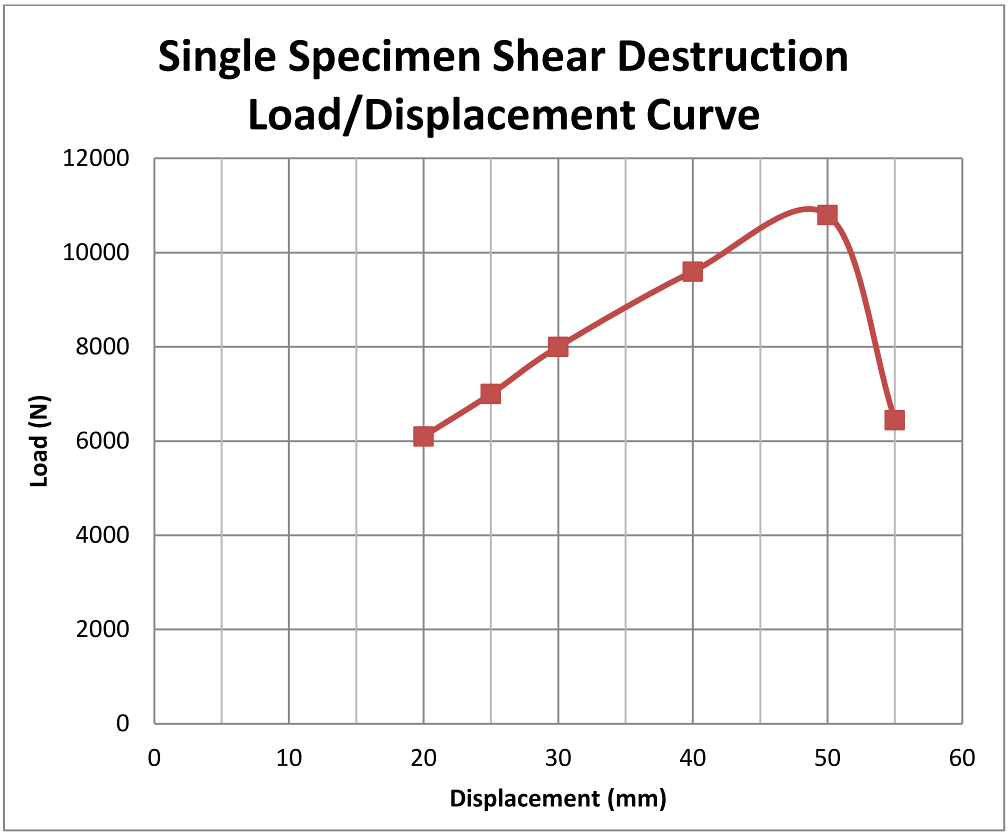


Figure 34. Load deflection curve for shear test of a single specimen to upper limits

Figure 35. Final failure mode in axial tension – failure is due to splitting of the timber, the connector still holds and the screws are still connected to the joist sections.

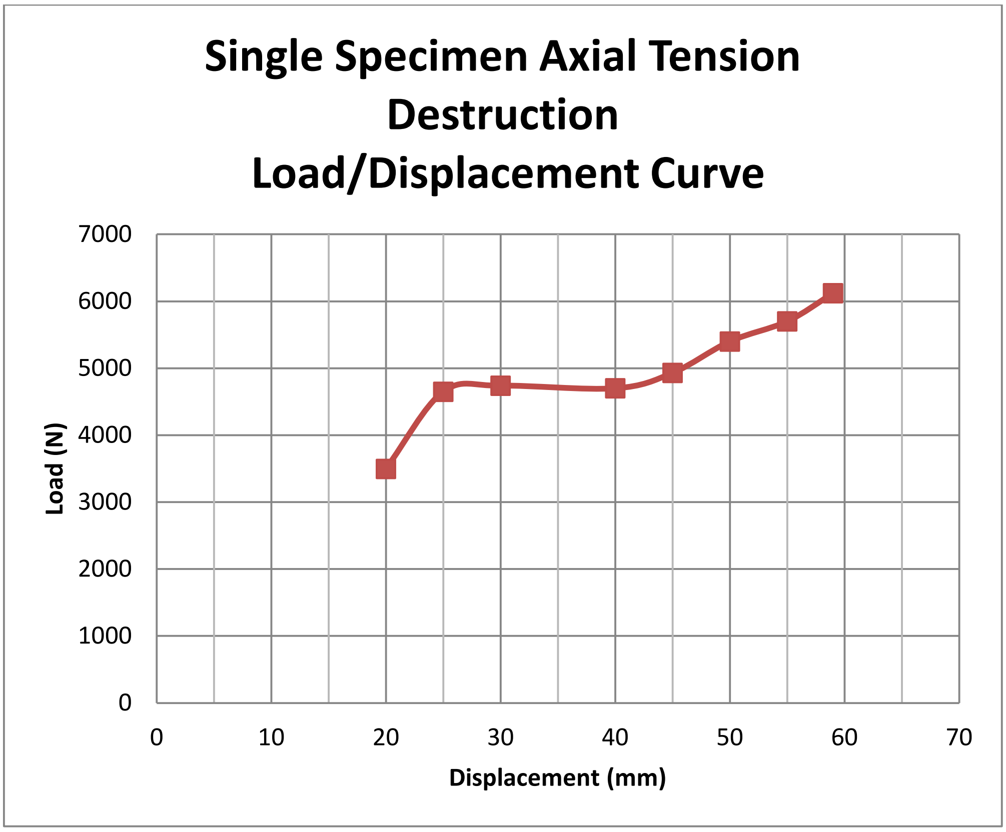


Figure 36. Load deflection curve for axial tension test of a single specimen to upper limits.

Figure 37. Final failure mode in axial tension – failure is due to splitting of the timber, the connector still holds and the screws are still connected to the joist sections.

Structural Testing Comments

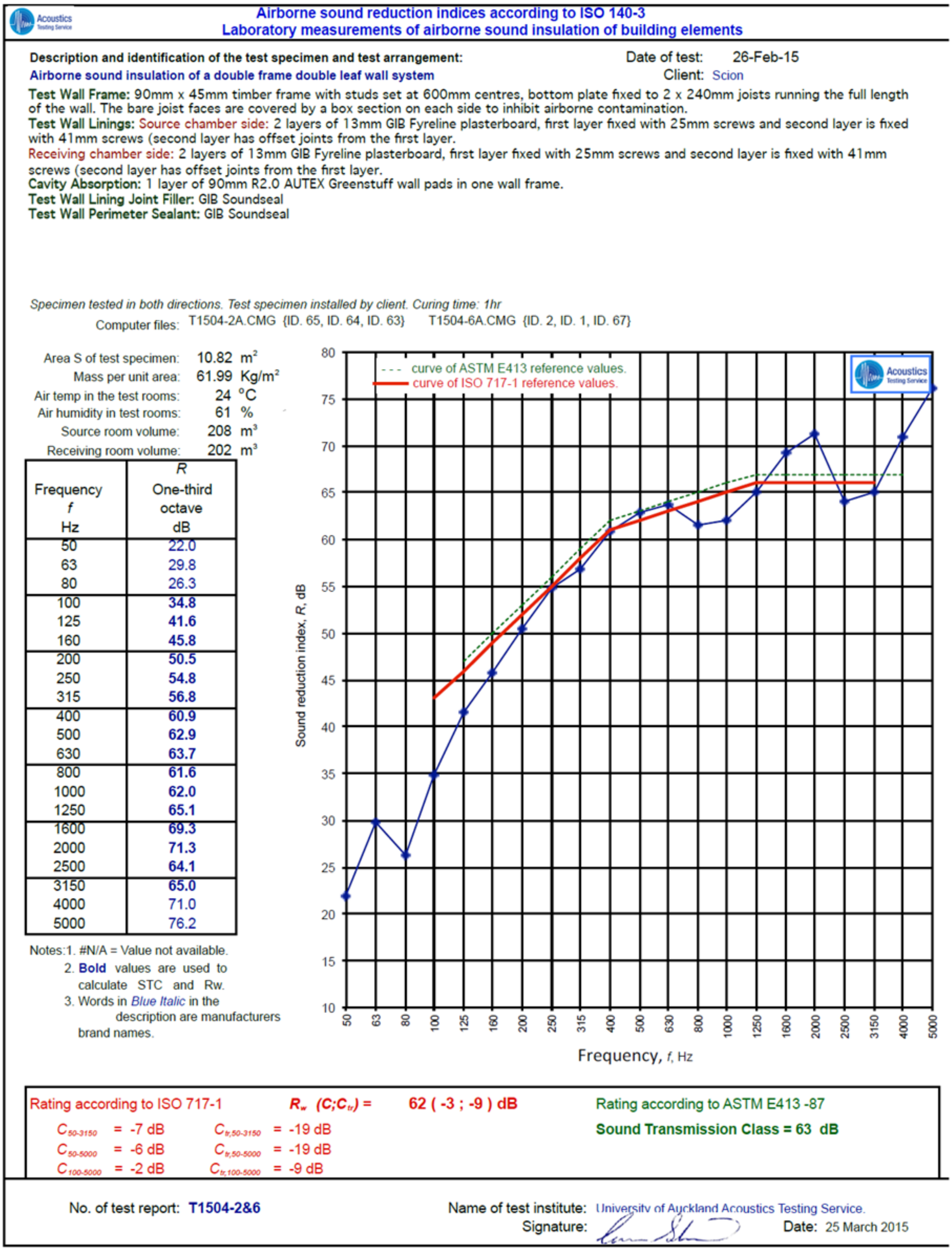
- No screw pull-out observed, but a little bending of screws in shear and hence slip of brackets.
- No observed bending of M10 bolt, only distortion of plate at bolt anchor point.
- Some roll of the bracket and flexure in axial tension have caused the tension results to be less than expected. Another screw at the back of the plate may stop this.

Conclusion

- The in wall acoustic performance of the across-plate connector design is better than predicted, even when the brackets were compressed to provide full contact of the front foam pads. For a connector every 600mm worst overall (STC, Rw) performance reduction (when connectors were compressed beyond the low-stiffness stage) was 1dB for a standard intertenancy double-stud wall with 2 layers of 13mm GIB Fyreline each side (STC=63dB, Rw = 62dB).
- Average load transfer at SLS (assumed to be 2mm displacement) was 500N in shear, and axial tension and compression.
- Average load transfer at ULS (assumed to be 10mm displacement) was 3300N in shear, 2100N in axial tension and 2800N in axial compression.
- Load / Displacement performance was less than expected for axial tension due to rolling of the bracket and flexure. A different screwing pattern may stop this.
- Cost for each unit was about $100 ($80 for steel and folding, $10 for resilient urethane and water jet cutting, $10 for bolt, nuts and Rothoblaas attachment screws)

Appendix A: Auckland University Acoustic Results

Basic double-stud wall - no connectors across the bottom plates



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

Description and identification of the test specimen and test arrangement: Date of test: 26-Feb-15

Airborne sound insulation of a double frame double leaf wall system Client: Scion

Test Wall Frame: 90mm x 45mm timber frame with studs set at 600mm centres, bottom plate fixed to 2 x 240mm joists running the full length of the wall. The bare joist faces are covered by a box section on each side to inhibit airborne contamination.
Test Wall Linings: Source chamber side: 2 layers of 13mm GIB Fyreline plasterboard, first layer fixed with 25mm screws and second layer is fixed with 41mm screws (second layer has offset joints from the first layer.
Receiving chamber side: 2 layers of 13mm GIB Fyreline plasterboard, first layer fixed with 25mm screws and second layer is fixed with 41mm screws (second layer has offset joints from the first layer.
Cavity Absorption: 1 layer of 90mm R2.0 AUTEX Greenstuff wall pads in one wall frame.
Test Wall Lining Joint Filler: GIB Soundseal
Test Wall Perimeter Sealant: GIB Soundseal

Specimen tested in both directions. Test specimen installed by client. Curing time: 1hr

Computer files: T1504-2A.CMG {ID. 65, ID. 64, ID. 63} T1504-6A.CMG {ID. 2, ID. 1, ID. 67}

Area S of test specimen: 10.82 m^2
Mass per unit area: 61.99 Kg/m^2
Air temp in the test rooms: 24 °C
Air humidity in test rooms: 61 %
Source room volume: 208 m^3
Receiving room volume: 202 m^3

Frequency f Hz	R One-third octave dB
50	22.0
63	29.8
80	26.3
100	**34.8**
125	**41.6**
160	**45.8**
200	**50.5**
250	**54.8**
315	**56.8**
400	**60.9**
500	**62.9**
630	**63.7**
800	**61.6**
1000	**62.0**
1250	**65.1**
1600	**69.3**
2000	**71.3**
2500	**64.1**
3150	**65.0**
4000	71.0
5000	76.2

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

Rating according to ISO 717-1 **R_w (C;C_{tr}) = 62 (-3 ; -9) dB**

$C_{50\text{-}3150}$ = -7 dB $C_{tr,50\text{-}3150}$ = -19 dB
$C_{50\text{-}5000}$ = -6 dB $C_{tr,50\text{-}5000}$ = -19 dB
$C_{100\text{-}5000}$ = -2 dB $C_{tr,100\text{-}5000}$ = -9 dB

Rating according to ASTM E413 -87
Sound Transmission Class = 63 dB

No. of test report: **T1504-2&6**

Name of test institute: University of Auckland Acoustics Testing Service.
Signature:
Date: 25 March 2015

Wall with a across-plate connector every stud spacing (600mm) uncompressed (normal mode of operation with no loading).

Sound reduction index, R, in accordance with ISO 10140-2
Laboratory measurements of airborne sound insulation of building elements

Description and identification of the test specimen and test arrangement:

Date of test: 25-Feb-15

Airborne sound insulation of a Double leaf double frame wall

Client: Scion

Test Wall Frame: 90mm x 45mm timber frame with studs set at 600mm centres, bottom plate fixed to 2 x 240mm joists running the full length of the wall. The bare joist faces are covered by a box section on each side to inhibit airborne contamination. 1 x *Acoustic Structural Connector* screw fixed between each set of studs on the bottom plates, fixed to and bridging the two wall frames.
Test Wall Linings: Source chamber side: 2 layers of *13mm GIB Fyreline* plasterboard, first layer fixed with 25mm screws and second layer is fixed with 41mm screws (second layer has offset joints from the first layer.
Receiving chamber side: 2 layers of *13mm GIB Fyreline* plasterboard, first layer fixed with 25mm screws and second layer is fixed with 41mm screws (second layer has offset joints from the first layer.
Cavity Absorption: 1 layer of 90mm *R2.0 AUTEX Greenstuff wall pads* in one wall frame.
Test Wall Lining Joint Filler: *GIB Soundseal*
Test Wall Perimeter Sealant: *GIB Soundseal*

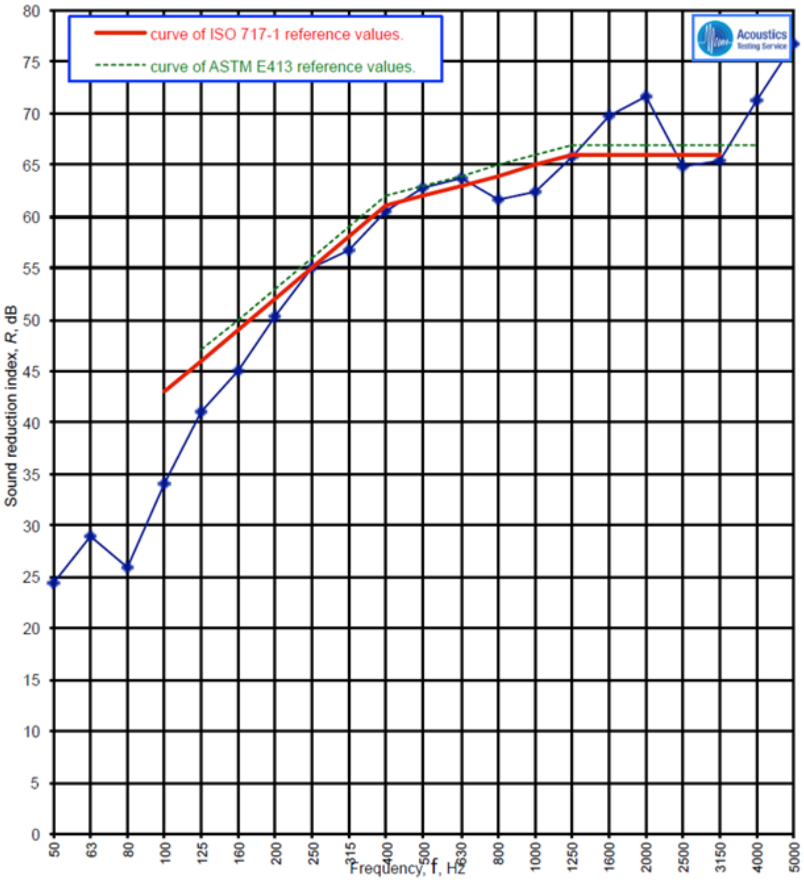
Source chamber: Chamber C, Receiving chamber: Chamber A . Test specimen installed by client. Curing time: 3hrs

Computer files: Emmited noise: T1504-3A.CMG: ID.2 Received noise: T1504-3A.CMG: ID.1 Reverberation time: T1504-3A.CMG: ID.0

Area *S* of test specimen:	10.82 m²
Mass per unit area:	63.01 kg/m²
Air temp in the test rooms:	24 °C
Air humidity in test rooms:	60 %
Source room volume:	208 m³
Receiving room volume:	202 m³

Frequency *f* Hz	*R* One-third octave dB
50	24.4
63	28.9
80	25.9
100	**34.0**
125	**41.0**
160	**45.0**
200	**50.3**
250	**55.0**
315	**56.7**
400	**60.5**
500	**62.7**
630	**63.7**
800	**61.6**
1000	**62.5**
1250	**65.9**
1600	**69.7**
2000	**71.7**
2500	**64.8**
3150	**65.5**
4000	71.3
5000	76.7

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



Rating according to ISO 717-1 R_w $(C;C_{tr})$ = 62 (-3 ; -10) dB

$C_{50\text{-}3150}$ = -7 dB $C_{tr,\ 50\text{-}3150}$ = -18 dB
$C_{50\text{-}5000}$ = -6 dB $C_{tr,\ 50\text{-}5000}$ = -18 dB
$C_{100\text{-}5000}$ = -2 dB $C_{tr,100\text{-}5000}$ = -10 dB

Rating according to ASTM E413 -87
Sound Transmission Class = 63 dB

No. of test report: **T1504-3A**

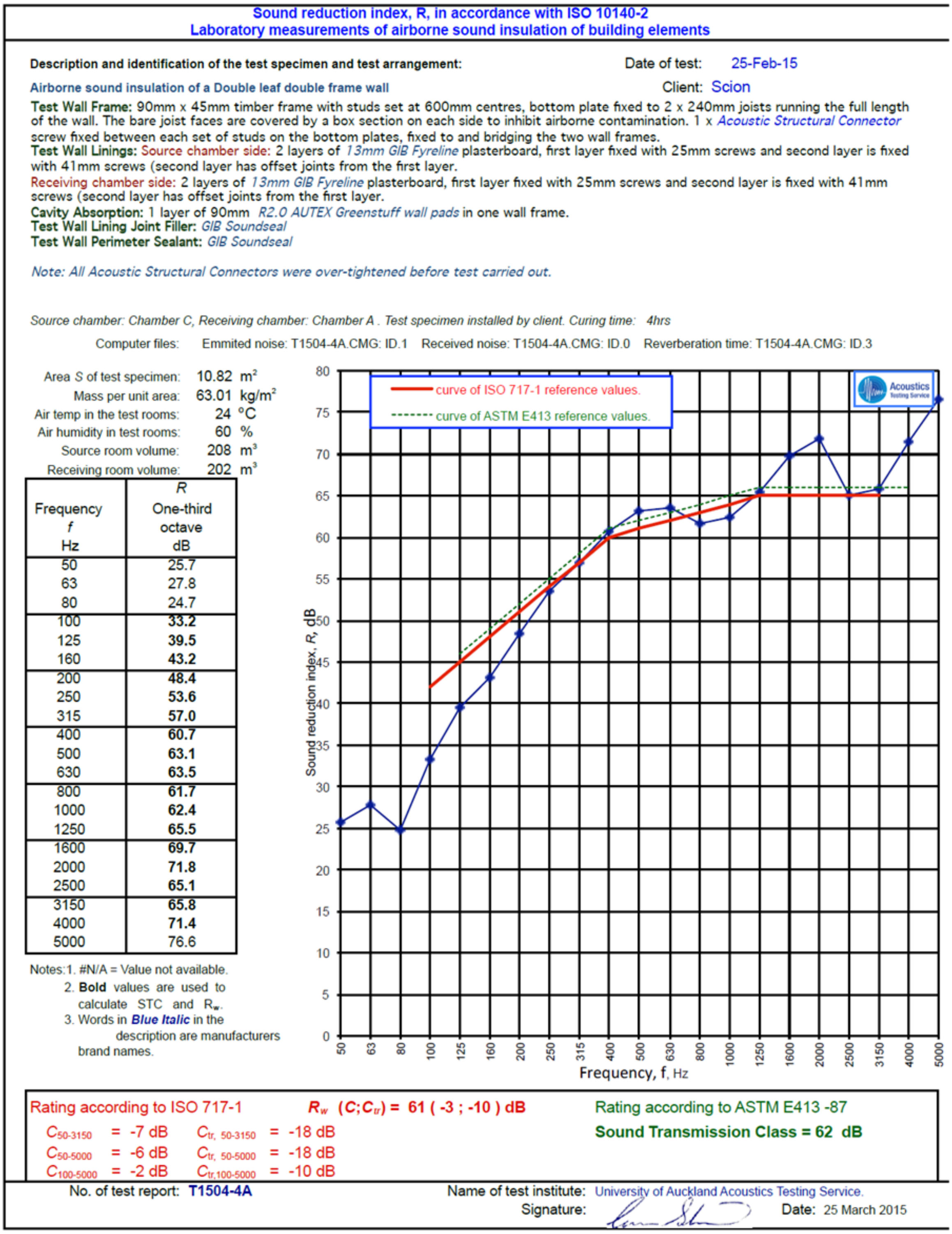
Name of test institute: University of Auckland Acoustics Testing Service.

Signature:

Date: 25 March 2015

Acoustics Testing Service

A connector every stud spacing (600mm) compressed to simulate a constant load which compresses the connectors beyond 1mm into a stiffer region of operation.



Sound reduction index, R, in accordance with ISO 10140-2
Laboratory measurements of airborne sound insulation of building elements

Description and identification of the test specimen and test arrangement: Date of test: 25-Feb-15

Airborne sound insulation of a Double leaf double frame wall Client: Scion

Test Wall Frame: 90mm x 45mm timber frame with studs set at 600mm centres, bottom plate fixed to 2 x 240mm joists running the full length of the wall. The bare joist faces are covered by a box section on each side to inhibit airborne contamination. 1 x *Acoustic Structural Connector* screw fixed between each set of studs on the bottom plates, fixed to and bridging the two wall frames.
Test Wall Linings: Source chamber side: 2 layers of *13mm GIB Fyreline* plasterboard, first layer fixed with 25mm screws and second layer is fixed with 41mm screws (second layer has offset joints from the first layer.
Receiving chamber side: 2 layers of *13mm GIB Fyreline* plasterboard, first layer fixed with 25mm screws and second layer is fixed with 41mm screws (second layer has offset joints from the first layer.
Cavity Absorption: 1 layer of 90mm *R2.0 AUTEX Greenstuff wall pads* in one wall frame.
Test Wall Lining Joint Filler: *GIB Soundseal*
Test Wall Perimeter Sealant: *GIB Soundseal*

Note: All Acoustic Structural Connectors were over-tightened before test carried out.

Source chamber: Chamber C, Receiving chamber: Chamber A . Test specimen installed by client. Curing time: 4hrs

Computer files: Emmited noise: T1504-4A.CMG: ID.1 Received noise: T1504-4A.CMG: ID.0 Reverberation time: T1504-4A.CMG: ID.3

Area *S* of test specimen:	10.82 m²
Mass per unit area:	63.01 kg/m²
Air temp in the test rooms:	24 °C
Air humidity in test rooms:	60 %
Source room volume:	208 m³
Receiving room volume:	202 m³

Frequency *f* Hz	*R* One-third octave dB
50	25.7
63	27.8
80	24.7
100	**33.2**
125	**39.5**
160	**43.2**
200	**48.4**
250	**53.6**
315	**57.0**
400	**60.7**
500	**63.1**
630	**63.5**
800	**61.7**
1000	**62.4**
1250	**65.5**
1600	**69.7**
2000	**71.8**
2500	**65.1**
3150	**65.8**
4000	71.4
5000	76.6

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

Rating according to ISO 717-1 R_w $(C;C_{tr})$ = 61 (-3 ; -10) dB

$C_{50\text{-}3150}$ = -7 dB $C_{tr,\ 50\text{-}3150}$ = -18 dB
$C_{50\text{-}5000}$ = -6 dB $C_{tr,\ 50\text{-}5000}$ = -18 dB
$C_{100\text{-}5000}$ = -2 dB $C_{tr,100\text{-}5000}$ = -10 dB

Rating according to ASTM E413 -87
Sound Transmission Class = 62 dB

No. of test report: **T1504-4A**

Name of test institute: University of Auckland Acoustics Testing Service.
Signature:
Date: 25 March 2015

Appendix B: Existing connection systems review

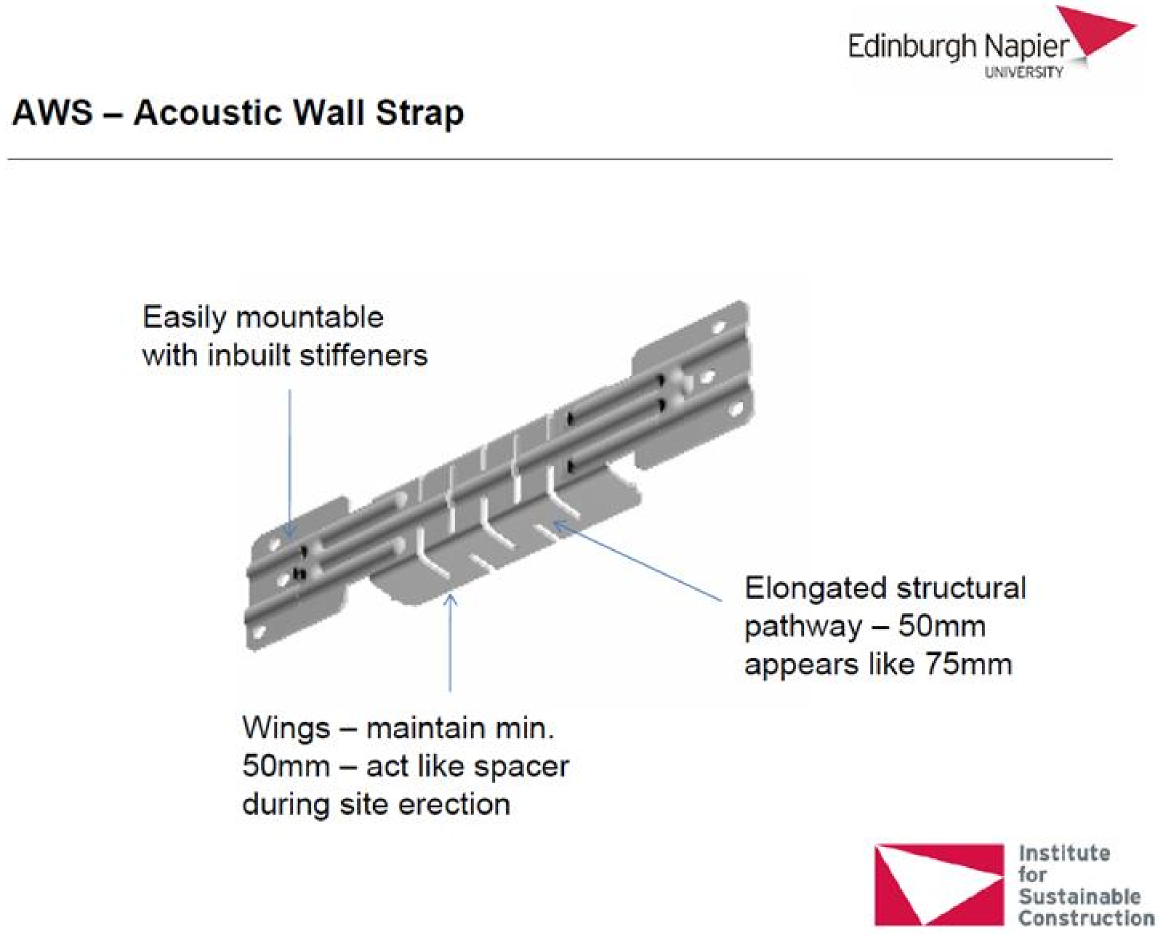
A desktop search was conducted among existing building connection systems that are acoustically isolating and/or structurally performing. The search provided different connecting systems that can be considered for the development of a new acoustically isolated structural connection system.

Commercial Acoustic/Structural Connectors

This section presents some of the available acoustic connectors for timber frame connections. Such connectors are specially designed for noise control.

Acoustic Wall Strap - Cullen Tech (ITW)

Developed in conjunction with Napier University, it uses slots in a metal connector to provide more vibration isolation. It is not clear how effective this would be.

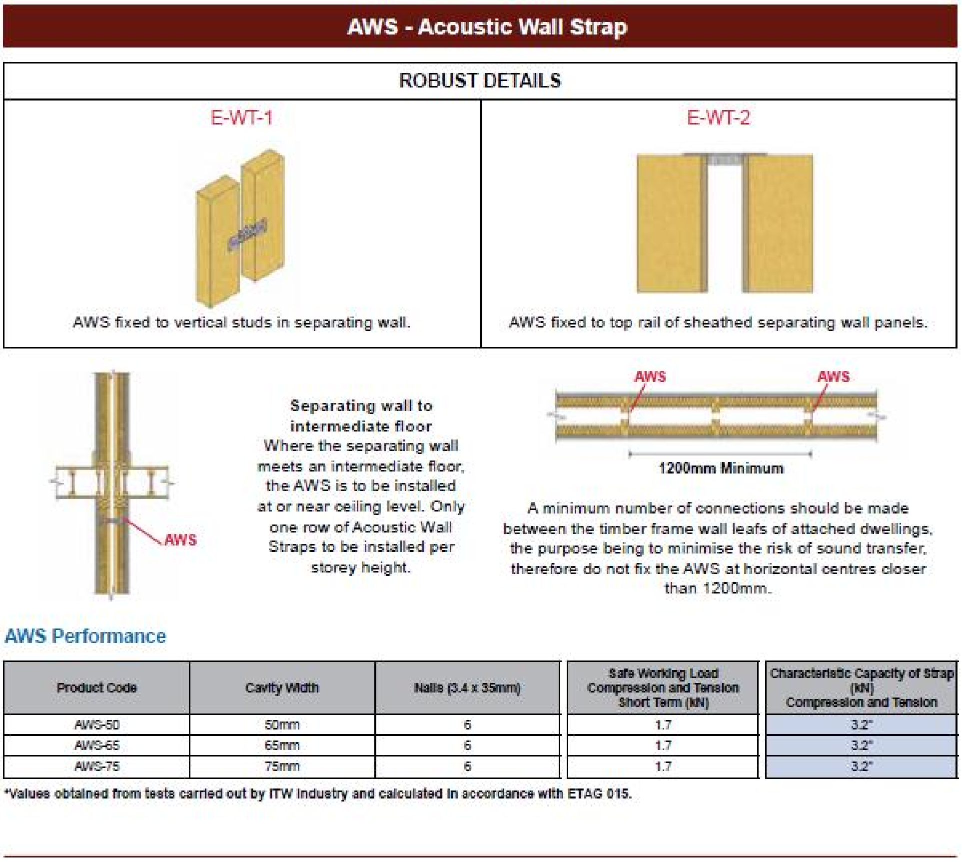


AWS – Acoustic Wall Strap

Easily mountable with inbuilt stiffeners

Elongated structural pathway – 50mm appears like 75mm

Wings – maintain min. 50mm – act like spacer during site erection



AWS - Acoustic Wall Strap

ROBUST DETAILS

E-WT-1	E-WT-2
AWS fixed to vertical studs in separating wall.	AWS fixed to top rail of sheathed separating wall panels.

Separating wall to intermediate floor
Where the separating wall meets an intermediate floor, the AWS is to be installed at or near ceiling level. Only one row of Acoustic Wall Straps to be installed per storey height.

A minimum number of connections should be made between the timber frame wall leafs of attached dwellings, the purpose being to minimise the risk of sound transfer, therefore do not fix the AWS at horizontal centres closer than 1200mm.

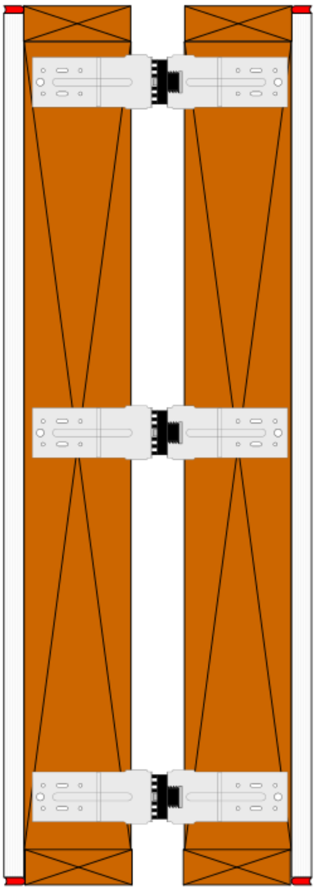
AWS Performance

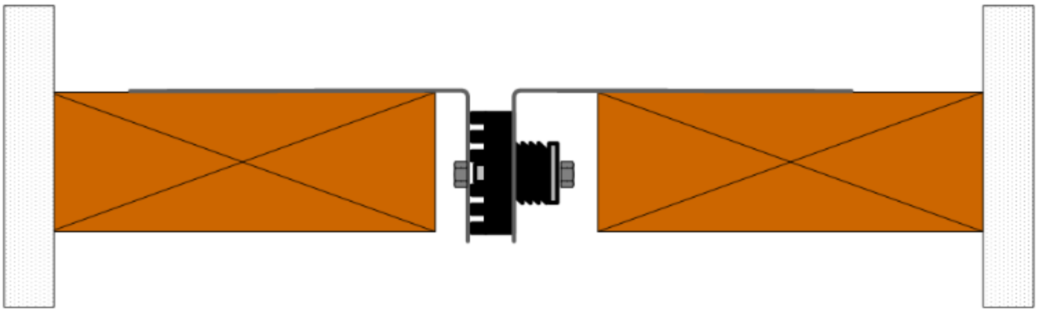
Product Code	Cavity Width	Nails (3.4 x 35mm)	Safe Working Load Compression and Tension Short Term (kN)	Characteristic Capacity of Strap (kN) Compression and Tension
AWS-50	50mm	6	1.7	3.2*
AWS-65	65mm	6	1.7	3.2*
AWS-75	75mm	6	1.7	3.2*

*Values obtained from tests carried out by ITW Industry and calculated in accordance with ETAG 015.

RSIC-CWB® Sound Isolation Clip

The RSIC-CWB™ has been used for several different acoustic needs. The most common use for this clip is to decouple two framed walls from each other. Some of the other uses are separating Brick or CMU walls from a framed wall to help ensure the two walls are isolated from each other.





Pasted from

http://www.pac-intl.com/pdf/Install_Guide_RSIC-CWBHD_DD.pdf

GIB® Quiet Tie® distributed by MiTek New Zealand

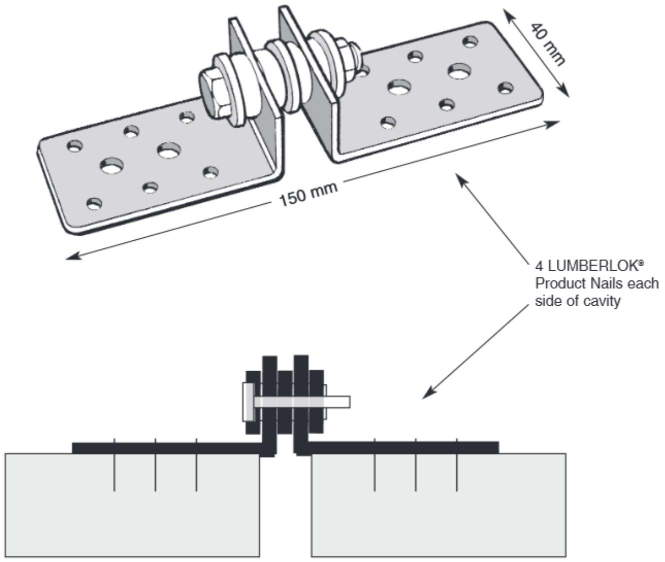
GIB® Quiet Tie® has been designed to provide a structural connection between the frames of double stud walls, whilst maintaining the STC rating of the system. No reduction in sound transmission loss is expected for double frame walls up to STC 68.

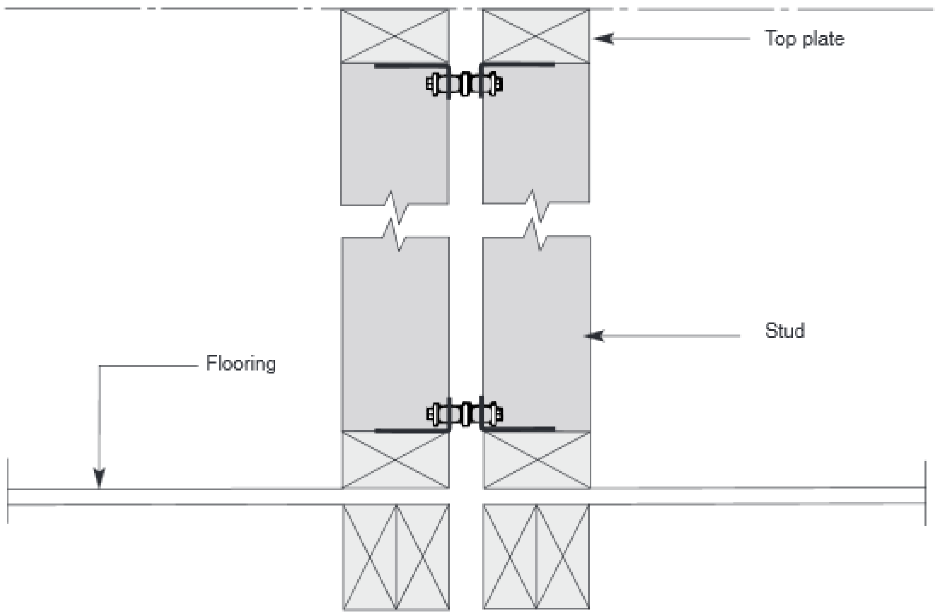
GIB® Quiet Tie® to control independent lateral movement of adjacent floors during an earthquake, resulting in unpredictable impact loads. Specific design is required to determine the appropriate spacing of the GIB® Quiet Tie®.

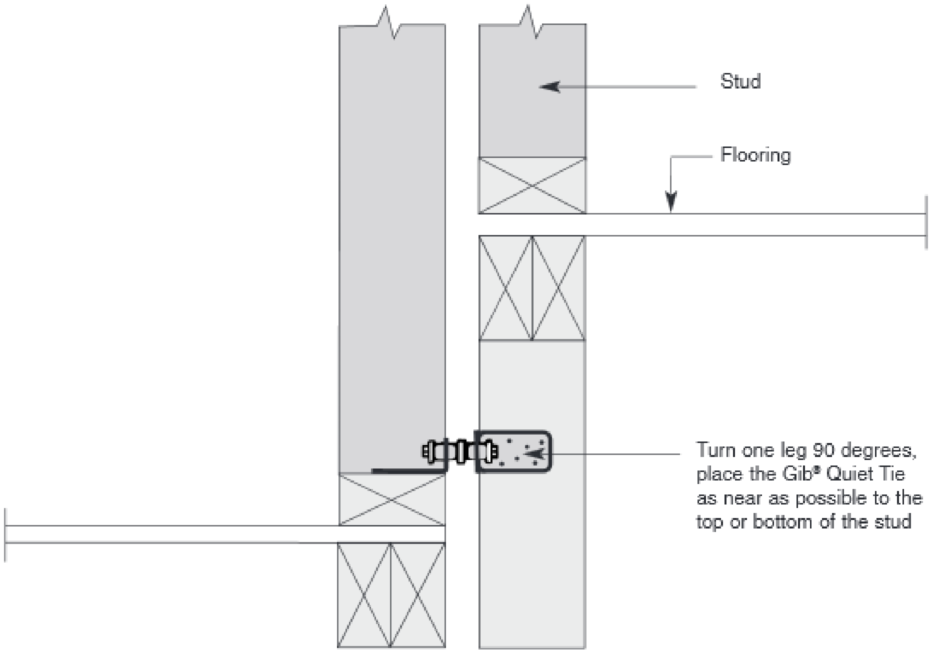
The GIB® Quiet Tie® has a design capacity of 4 kN in tension and 2 kN in compression (compression loads will also be partially absorbed by mineral fibre packing between frames at floor levels).

The GIB® Quiet Tie® provides tension and compression transfer capability but does not transfer shear loads between individual frames.(Beattie, Buchannan, Gaunt, & Soja, 200)

Connections are also required to ensure that the stability of double frame walls is maintained in the case of a fire on one side of the wall. New Zealand Loadings Standard NZS 4203:1992, Clause 2.4.3.4 addresses this issue.







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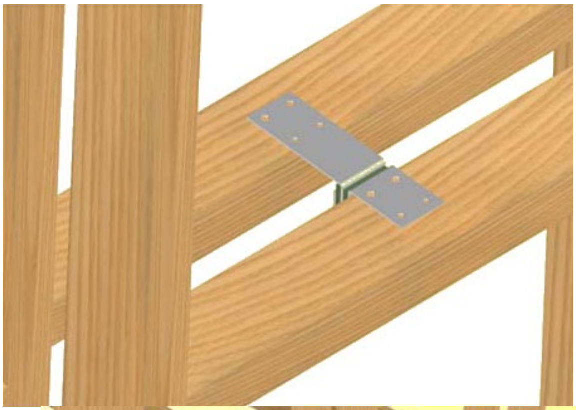
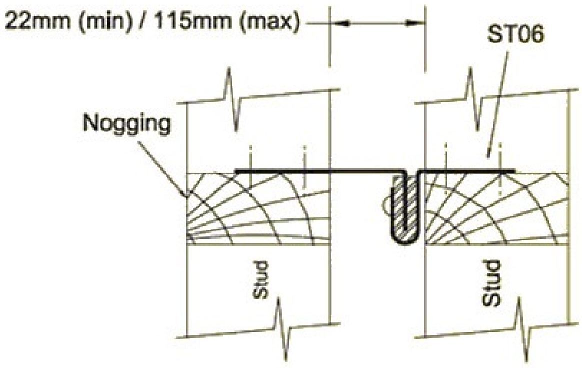
http://gib.co.nz/products/acoustic-accessories/gib-quiet-tie/
https://gib.co.nz/assets/Uploads/13.-Double-Frame-GIB-Quiet-Tie-System.pdf
https://www.mii.com/artefact/download.asp?aid=67007

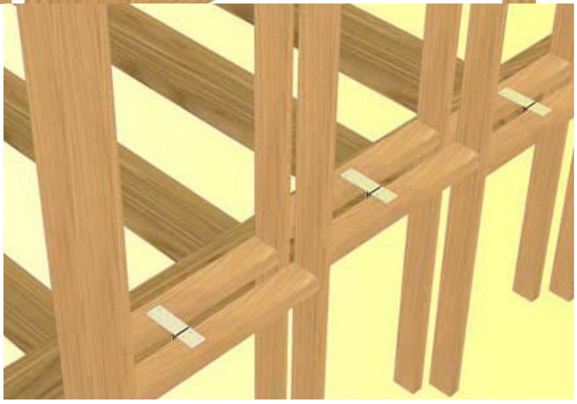
SB06 - Matrix Industries Pty Ltd

Matrix Industries SB06 wall ties comply with Australian Standard 2699:1:2000 “Wall Ties”. They are capable of transferring structural lateral forces from one leaf to the other. They are classified as a medium duty cavity tie with a minimum characteristic strength of 400 Newtons (N) in tension and 480 N in compression. SB06 ties can accept 10mm differential movement between the inner and outer leaves in both the transverse and vertical directions without loss of strength.

SB06 resilient wall ties were assessed in field tests comparing identical isolated and non-isolated rooms within the same building.







SB03 – Acoustic Wall Tie- Matrix Industries Pty Ltd

The SB03 acoustic wall tie is suitable for stud walls that require a resilient mount to attach the walls to the underside of slabs or upper floors structurally yet maintaining acoustic and impact isolation.

This connection will provide support to a stud wall along its top plate and will attach to a masonry wall or underside of a slab.

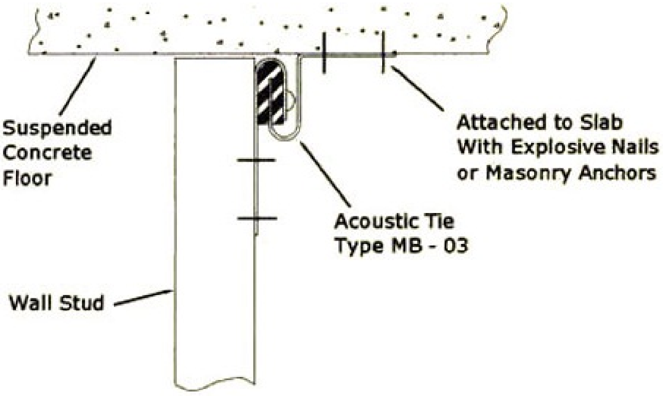
Lateral support for studs at mid height of high walls.

Minimum separation between wall leaves: 22mm.

Maximum lateral load: 0.25 kN.

Stiffness: 0.7 kN/mm (linear) up to 0.16 kN

Maximum deflection of resilient material: 2.3 mm.



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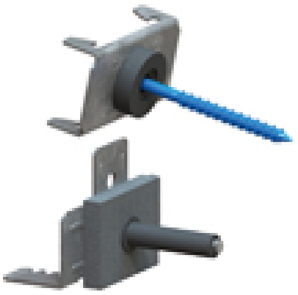
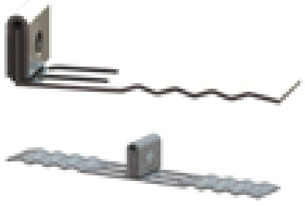
http://matrixindustries.com.au/products/sb03/

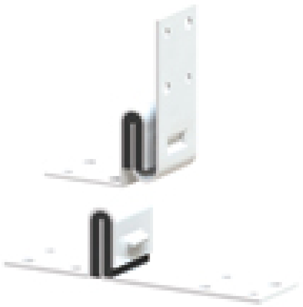
Embleton's range of products



Wall Isolation Type WC Series
Provides a resilient connection between furring channels and masonry walls. A rubber element helps reduce noise and vibration transmission though a wall cavity.
Load Range:
Tension: 220N
Shear: 780N

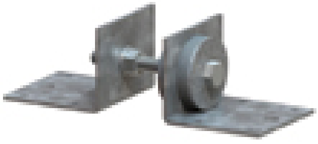


Wall Isolation Type MB Series
Provides a resilient connection between furring channels and masonry or stud walls for axial loads only. A cheap, light duty solution.
Load Range:
Tension: 400N
Compression: 480N



Wall Isolation Type SB Series
An inexpensive, light duty wall tie which provides a resilient connection between stud walls or stud to joist. Contains a foam isolating element.
Load Range:
Tension: 250-400N
Compression: 400-480N

Wall Isolation Type 310 Series
Medium duty wall tie which provides a resilient connection between wall members. Features a rugged steel bracket with a Shearflex isolating element. For axial loads only, 310 is for general purpose use, 310DM is for masonry walls only.
Max Axial Load: 500N
Horizontal Stiffness: 400N/mm



Wall Isolation Type HWTD-1
Medium duty wall tie which provides a higher degree of transmission isolation between wall members. Used for axial loads only, typically used in cinemas and recording studios.
Max Axial Load: 600N
Deflection: ±1mm
Precompressed to 2mm deflection.

Wall Isolation Type WTHE/WTHES
Medium duty wall tie which provides a high degree of transmission isolation between wall members. Used for axial loads only, typically used in cinemas and recording studios.
Max Axial Load: 0.5-1.25kN
Deflection: ±2.5mm
Axial Length: 75-102mm

Wall Isolation Type WTGI
Used for isolation between vertical structural columns and horizontal girt beams, with a degree of lateral restraint along with axial deflection.
Max Axial Load: 3.3kN
Max Lateral Load: 1kN
Deflection:
Axial: 2mm
Lateral: 1mm

Wall Isolation Type WTRW
Heavy duty wall tie which provides a high degree of transmission isolation between wall members. Used for axial loads only, typically used where high loads occur in cinemas and recording studios.
Axial Load:
Short Term: ±2.5-7.5kN
Long Term: ±1.5-4.6kN
Deflection: ±2mm

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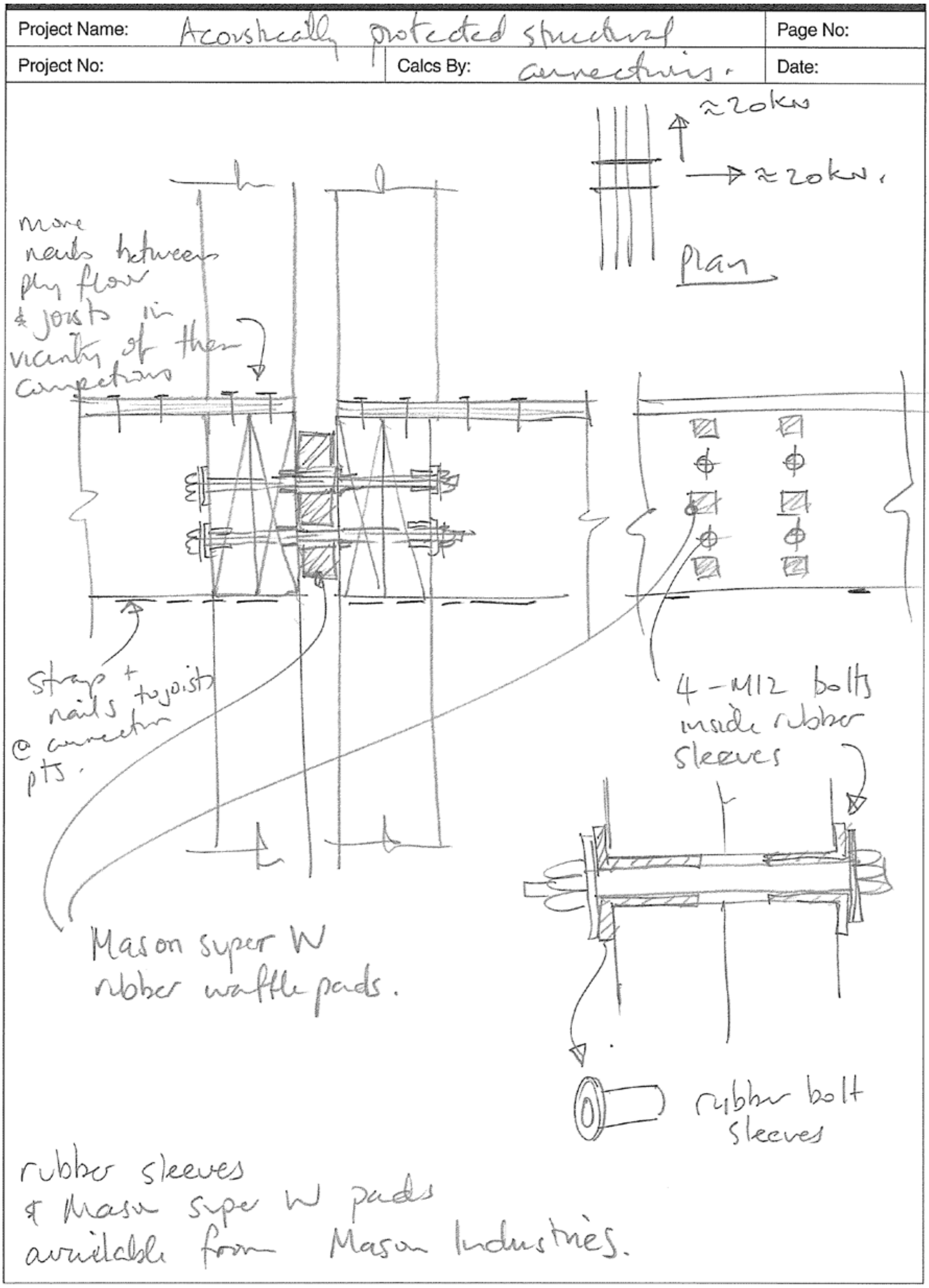
Custom designed example Warwick Banks

Warwick Banks‘ custom design for an acoustically protected structural connection for a terraced house in Wellington. Courtesy of Warwick Banks.



Project Name: Acoustically protected structural connections.

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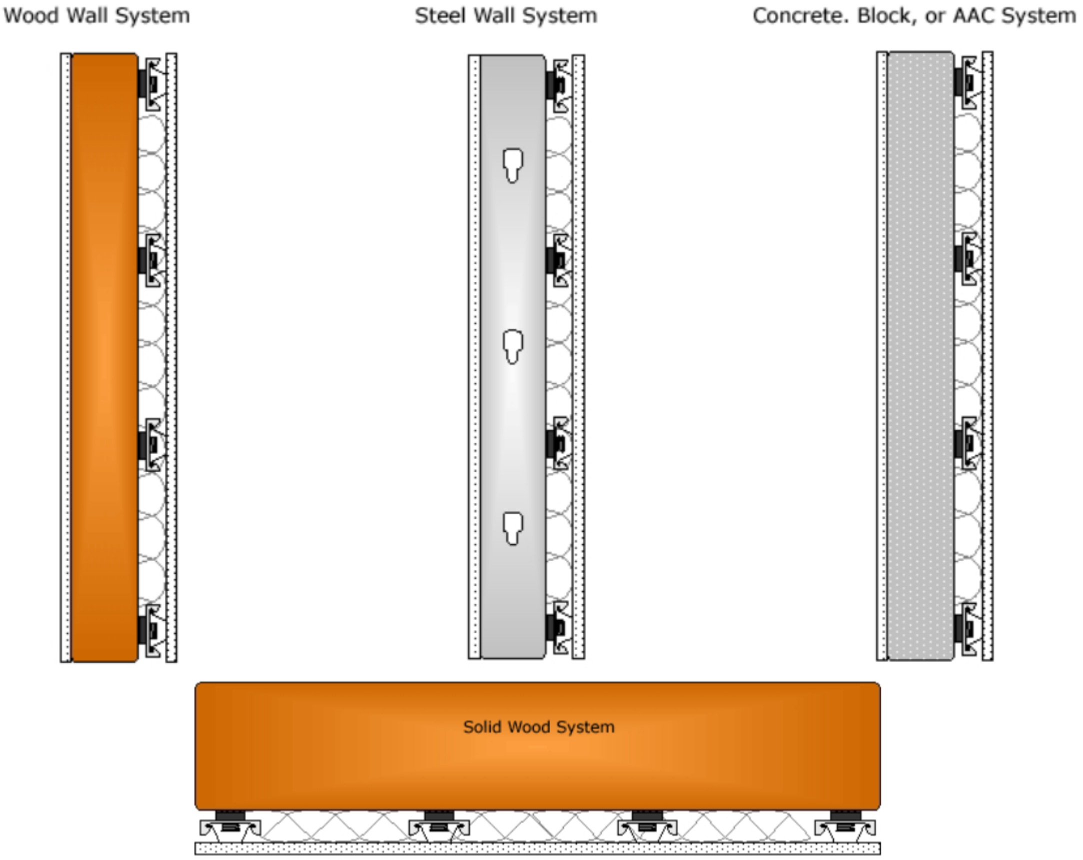
rubber sleeves
& Mason super W pads
available from Mason Industries.

Commercial Acoustic Connectors

This section presents some of the available acoustic connectors for interior linings. Such connectors are specially designed for noise control. Being fixing systems for interior finishes they are not designed to improve the building structure's strength.

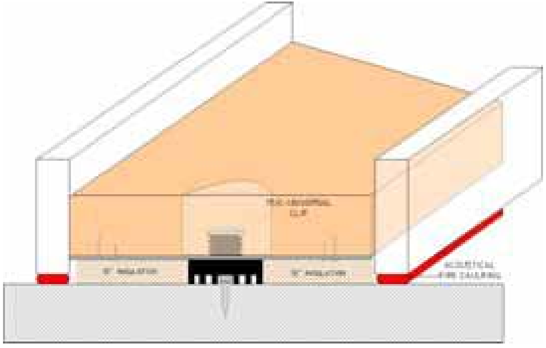
RSIC-1® Resilient Sound Isolation - PAC International, Inc.

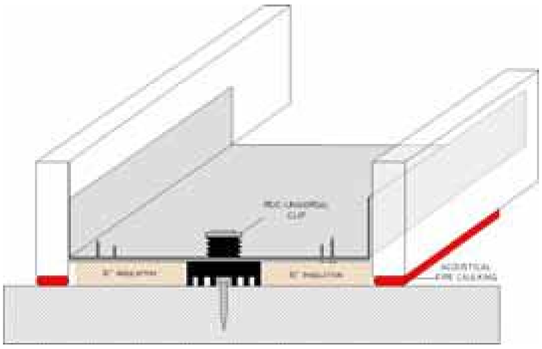
The RSIC-1 is designed for use with any wood framed, steel framed, CMU, or concrete wall and ceiling system where noise control is needed. The RSIC-1 assembly decouples and isolates the gypsum board or plywood from the structure increasing the acoustical performance of the system. With an Acoustical design load rating of 36 lbs per isolator, the RSIC-1 clip can support up to two layers of 5/8" gypsum board when spaced at 24" x 48" oc. For heavier systems increase the number of isolators to support the additional weight of the system. The RSIC-1 clip fastens directly to the framing or structure creating a 1-5/8" cavity between the face of the framing and the back of the gypsum board. The RSIC-1 stops the noise and vibrations that typically would be allowed to transfer throught the structure. The RSIC-1 systems have several UL fire resistive design assemblies from ranging one hour to four hours. The UL assemblies can be viewed on our site at http://pac-intl.com/fire_ratings_list.html, and on UL.com



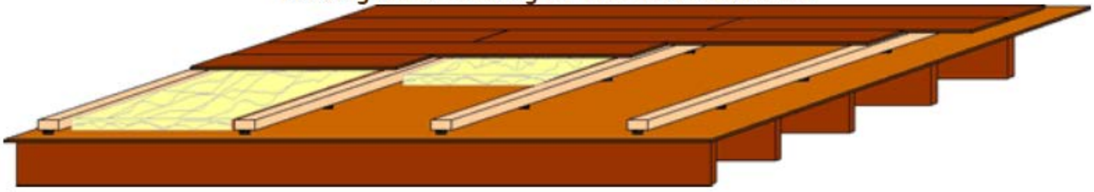
RSIC-U® and RSIC-U-HD® - PAC International Inc.

The RSIC-U (Resilient Sound Isolation) is a clip for isolating the wall to floor connection. It can be attached to CMU, steel, wood or concrete systems. The RSIC-U when used with the RSIC-1 isolation clips provides superior noise control in theatre and recording studio designs the walls need to be completely decoupled from the structure. The RSIC-U clip decouples the walls from the structure and the RSIC-1 clips decouple the gypsum board from the wall, completely eliminating the structure borne path of noise and ensuring the very best in noise control.

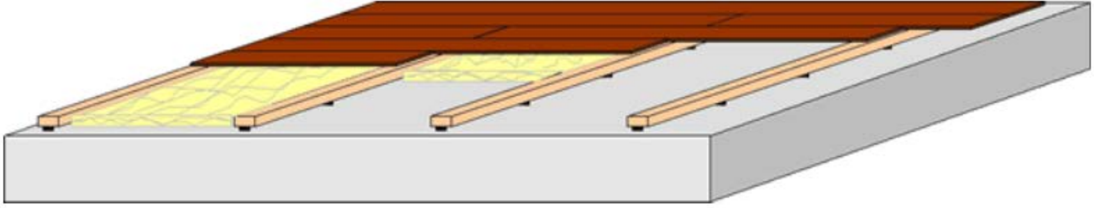




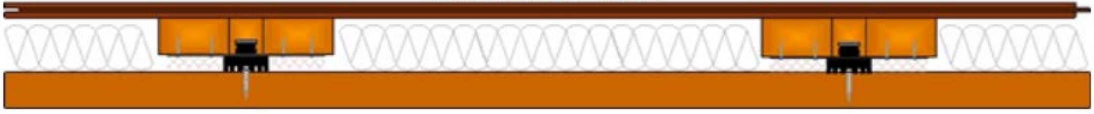
Floating Wood Flooring for Wood Framed Floors



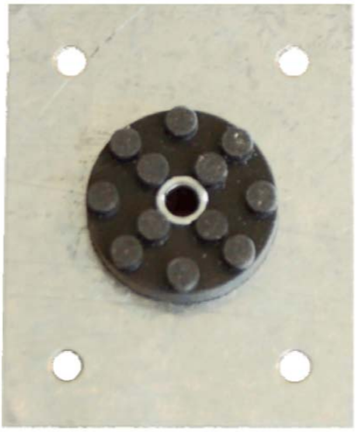
Floating Wood Flooring for Concrete Floors

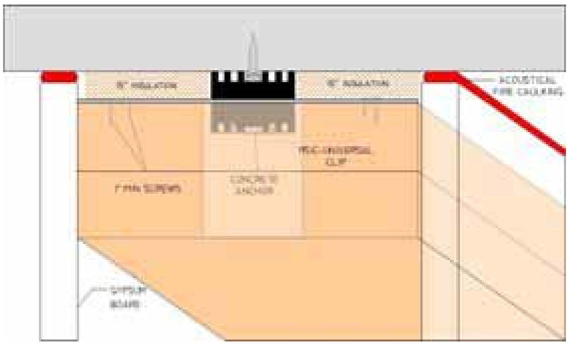


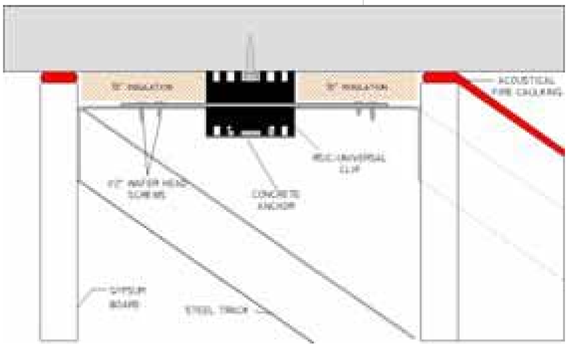
Floating Floor prifile



The RSIC-U-HD is a clip for isolating the ceiling to floor connection. It can be attached to CMU, steel, wood or concrete systems. The RSIC-U-HD when used with the RSIC-1 isolation clips provides superior noise control in theatre and recording studio designs the walls need to be completely decoupled from the structure. The RSIC-U-HD clip decouples the walls from the structure and the RSIC-1 clips decouple the gypsum board from the wall, completely eliminating the structure borne path of noise and ensuring the very best in noise control.







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http://soundisolationsystem.com/pdf/RSIC_products_flier.pdf
http://www.pac-intl.com/rsic-u.html

AFA - Acoustical Furring Attachment - Mason UK Ltd

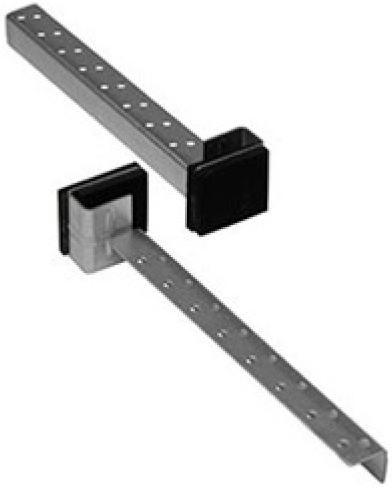
The AFA is an acoustical furring attachment for use with metal or wood stud walling. The AFA clamps the top hat section of the metal framing system to which boards are then attached

Pasted from
http://www.mason-uk.co.uk/acoustically-isolated-walls.asp#.VCyu0_mSxu2

Gypframe Acoustic Hangers and Acoustic Brace BPB United Kingdom Ltd trading as British Gypsum - Saint-Gobain

Resilient hangers used in conjunction with the CasoLine MF ceiling system and timber joist ceilings and floors for increased sound insulation.

Specially engineered product to optimise acoustic performance on the GypWall AUDIO system in high performance applications such as cinemas.



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http://www.british-gypsum.com/products/gypframe-acoustic-hangers
http://www.british-gypsum.com/products/gypframe-acoustic-brace

Commercial Masonry Acoustic Wall Ties

This section presents some of the available acoustic connectors for masonry construction. Such connectors are designed for noise control and to provide the structural strength to tie masonry walls to the building structure.

Mason UK Ltd range

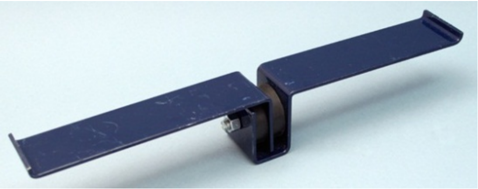
DNSB-A Sway Brace / Wall Tie

DNSB-A is a low frequency wall tie. It has a bolt end for stud walls or hooked end for masonry walls.
Click below to learn more.

Type & Size	Rated Axial Restraint & Deflection if Stressed Load [kg]	Defl. [mm]	Load [kg]	Defl. [mm]	Maximum Assigned Wall Weight	Minimum Assigned Weight to Establish 10 Hz
DNSB-A	25	2.5	38	3.8	113 kg	23 kg
DNSB-B	118	2.5	177	3.8	544 kg	181 kg

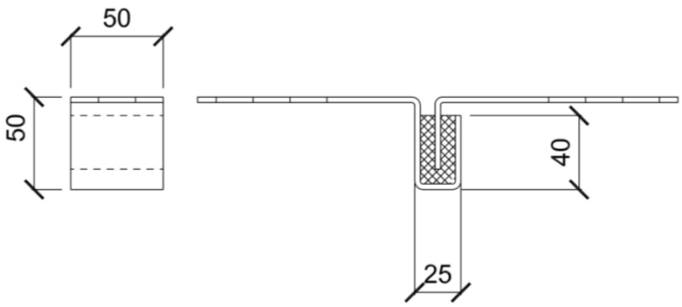
Resistance to Vertical Motion Created by Wall Pad or Floating Floor Deflection Load [kg]	Defl. [mm]	Load [kg]	Defl. [mm]	Load [kg]	Defl. [mm]	Load [kg]	Defl. [mm]
3	1.2	5	2.5	8	3.8	11	5.0
18	1.2	35	2.5	53	3.8	71	5.0

1. Sway braces prevent buckling or overturning of tall or long walls.
2. Buckling forces are extremely small when braces are reasonably spaced both horizontally and vertically as the brace spacing maintains a very low l/r column ratio.
3. Our general recommendation is spacing on four foot centers both horizontally and vertically.
4. The maximum axial restraint rating is approximately 33% of the maximum assigned wall weight and extremely conservative.
5. Vertical resistance information is provided for checking embedment requirements in walls and shear or pullout forces on both ends of the sway braces. Sway braces are not to be used for vertical supports.
6. Response frequency is a function of the attached mass and the dynamic stiffness in the direction of vibration.

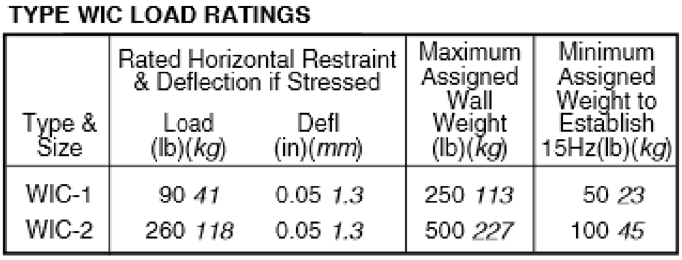


WIC-2-SM Sway Brace / Wall Tie

The Mason WIC-2-SM is a masonry wall tie designed to connect two masonry walls built together. No limit on cavity or wall thickness.



WIC Sway Brace / Wall Tie
The WIC acoustic sway brace is a low profile, low cost wall tie. Minimum cavity = 40mm
WIC acoustic wall braces are used when space is limited between the isolated wall and the main building structure.



TYPE WIC LOAD RATINGS

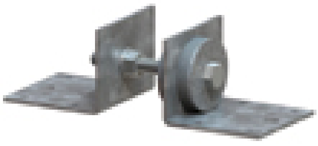
Type & Size	Rated Horizontal Restraint & Deflection if Stressed Load (lb)(*kg*)	 Defl (in)(*mm*)	Maximum Assigned Wall Weight (lb)(*kg*)	Minimum Assigned Weight to Establish 15Hz(lb)(*kg*)
WIC-1	90 *41*	0.05 *1.3*	250 *113*	50 *23*
WIC-2	260 *118*	0.05 *1.3*	500 *227*	100 *45*

KWSB2 - Kinetics Noise Control, Inc.

Anti-Buckling Resilient Partition Brace
Model KWSB2 Capable of withstanding a seismic generated force of 50 lbs.

Pasted from
http://www.kineticsnoise.com/arch/kwsb.html

Embleton's range of products



Wall Isolation Type HWTD-1
Medium duty wall tie which provides a higher degree of transmission isolation between wall members. Used for axial loads only, typically used in cinemas and recording studios.
Max Axial Load: 600N
Deflection: ±1mm
Precompressed to 2mm deflection.

Wall Isolation Type WTHE/WTHES
Medium duty wall tie which provides a high degree of transmission isolation between wall members. Used for axial loads only, typically used in cinemas and recording studios.
Max Axial Load: 0.5-1.25kN
Deflection: ±2.5mm
Axial Length: 75-102mm

Wall Isolation Type WTGI
Used for isolation between vertical structural columns and horizontal girt beams, with a degree of lateral restraint along with axial deflection.
Max Axial Load: 3.3kN
Max Lateral Load: 1kN
Deflection:
Axial: 2mm
Lateral: 1mm

Wall Isolation Type WTRW
Heavy duty wall tie which provides a high degree of transmission isolation between wall members. Used for axial loads only, typically used where high loads occur in cinemas and recording studios.
Axial Load:
Short Term: ±2.5-7.5kN
Long Term: ±1.5-4.6kN
Deflection: ±2mm

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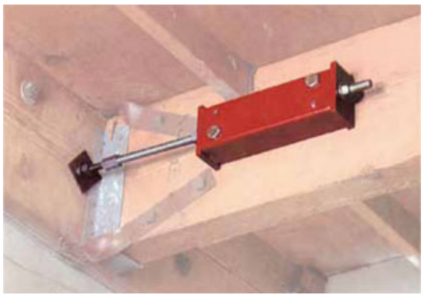
https://techlibrary.embelton.com/Resource/ResourceList.aspx?ID=9

Commercial Structural Connectors

This section presents some of the available structural connectors for timber frame buildings. Such connectors are designed to enhance the building's structural strength to earthquake and strong winds forces.

Hardy Frame range



Hardy Frame® Z4 CT Continuity Tie

The Hardy Frame® Z4 Continuity Tie is a quality bolted connection that transfers both tension and compression forces with minimal device deflection. It is typically installed in a roof diaphragm as a wall tie or continuity tie.

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http://www.hardyframe.com/z4_CT.htm

Hardy Frame® Z4 T2 Sandwich Connection

The Z4 Tension Tie when used between two wood posts is called a "Sandwich Connection". This unique assembly is a concentric connection with one device and two pieces of wood, optimizing the capacity of the bolts to the tensile capacity of the wood studs. By utilizing the Z4 Tension Tie the Sandwich benefits from accurately sized bolt holes, minimal device deflection, ductile failure modes, and ICC recognized allowable loads that include wood member capacities.

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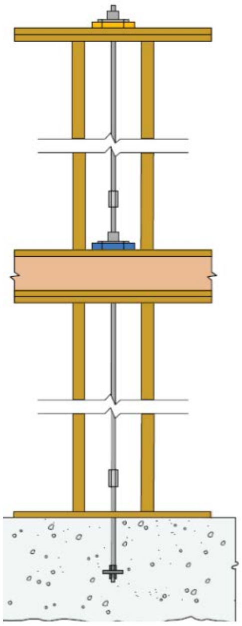
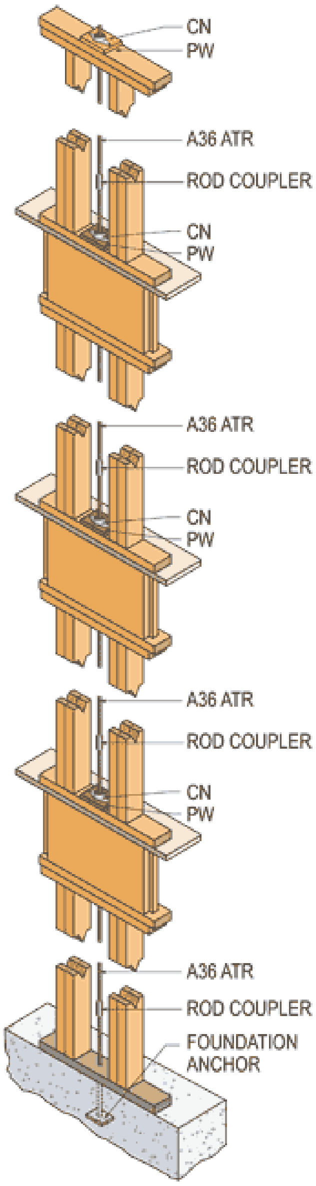
http://www.hardyframe.com/z4_sandwich.htm



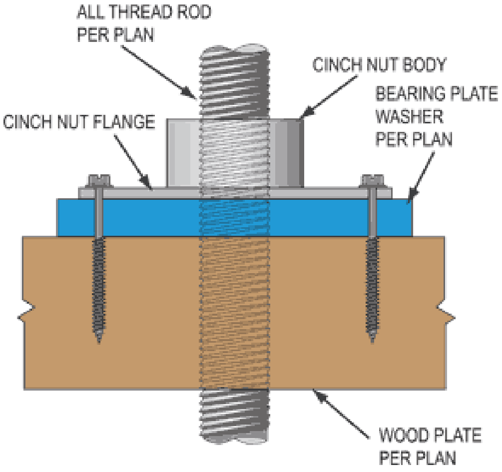


Hardy Frame® Z4 Quick-Connect Continuous Rod Tie-Down Systems

The Hardy Frame® Z4 Quick-Connect continuous rod system can be used for single and multi-family wood construction. This unique product features an innovative wood shrinkage device called a Cinch Nut, which offers perpetual shrinkage by ratcheting down threaded rod in the non-load direction. As a result, this device compensates for any wood settling, keeping shear walls tight and overturning to a minimum. Uplift forces are transferred to the rod from the Z4 Cinch Nut, which is anchored with two 1/4" lags against a concentric steel plate washer located above the wood top plate at each level. When loaded, the nut tightens against the steel threads with sufficient force to cause the rod to fail before the Cinch Nut. Additionally, the CN is not spring loaded and does not require activation or a second inspection from pulling pins or removing screws. Once the device is anchored to the wood member it is prepared for any seismic activity, wind, snow or earthquake.

Lateral Loads: To resist tension loads due to overturning moments in multi-story buildings the Z4 Cinch Nut is installed over a Bearing Plate at each level in a fast and easy “Quick Connect” application. At the upper-most level a Cinch Nut is installed over Bearing Plate above the top plates. At walls below that bear on wood floor systems the Cinch Nut and Bearing Plate is installed over the bottom plate. Tension loads are gathered at each level and transferred into the foundation through a continuous system of Cinch Nuts, Bearing Plates, threaded rods and coupling nuts, all available from Hardy Frame – Z4.

Wind Uplift: For resisting roof uplift loads resulting from wind the Z4 Cinch Nut is installed over a Bearing Plate above the top plates with roof framing above to create a tie-down system. Uplift forces are transferred into a continuous system of threaded rods and coupling nuts that form a load path to the foundation.



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http://www.hardyframe.com/z4_quickconnect.htm

Existing connection systems review conclusions

Existing commercial connection systems are resilient enough to not overly affect acoustic performance, but do not provide enough structural connection for extreme seismic or wind forces or vice versa.

No commercially available connecting system able to cope with demanding requirements in both acoustic and structural performances have been found. The analysis of existing connection systems therefore confirmed the lack of a commercial product filling this gap in the market.

A connection providing both acoustic performances and effective strength to resist those natural events is therefore needed to support the construction market’s stakeholders for the realisation of quality and resilient medium and high density housing.

Appendix C: Preliminary Design Details and Test Results

Two initial preiminary designs for connector systems were developed:

- **Through-joist connector**: A large load transfer design which can be connected through the edge joists (only a few units needed per apartment),
- **Across-plate connector**: A lower load transfer design which can be mounted on the bottom plates and spans across the double stud gap (the lesser load transfer would require that more units be used).

Through-joist connector

This system penetrates the edge joists. The SLS design aim is 4kN load transfer with 2mm displacement both tension/compression and in shear. The ULS design aim is 20kN with 10mm displacement both tension/compression and in shear.
Figure 38 and **Figure 39** show the design as tested.

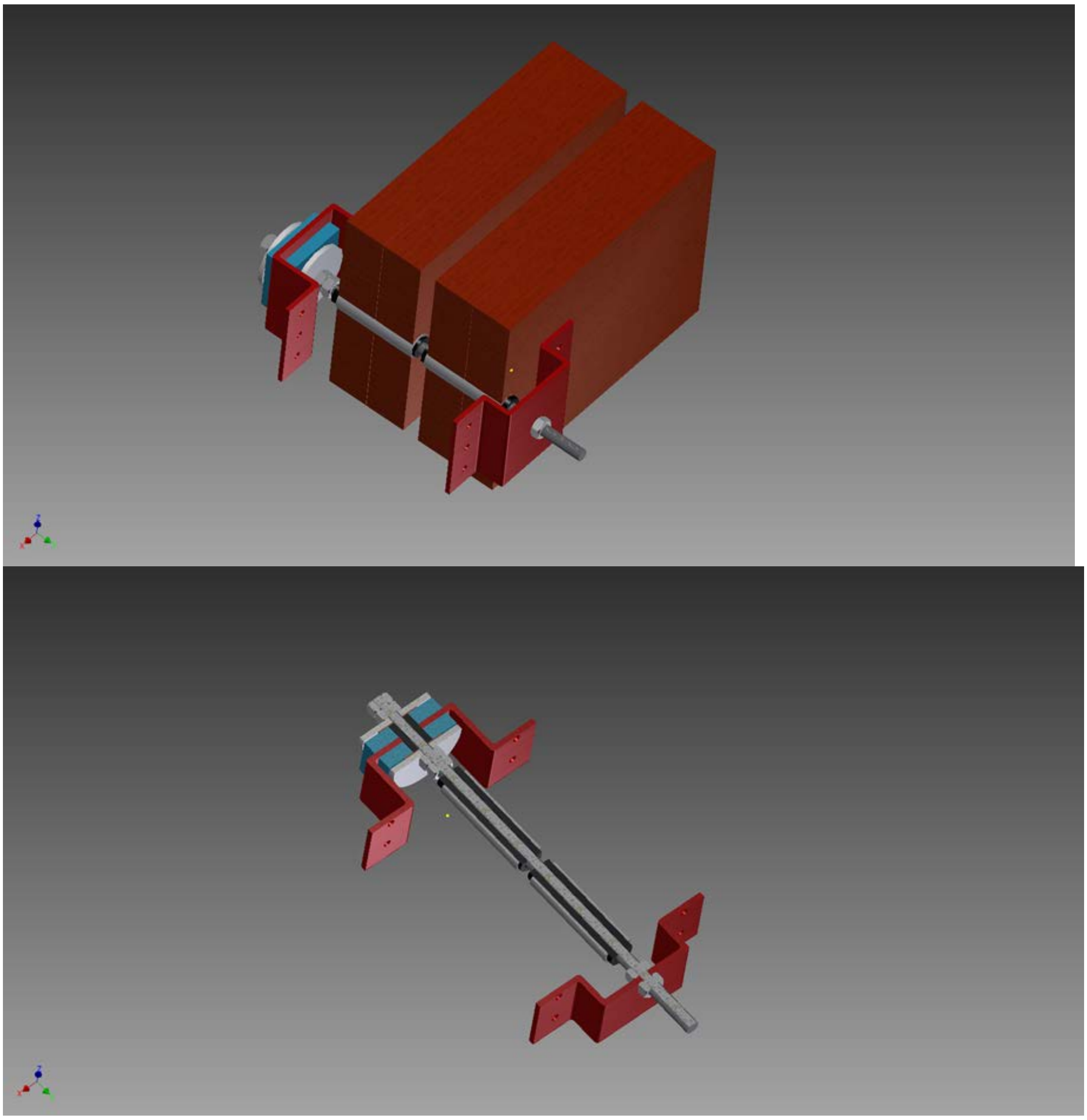


Figure 38. Through-joist connector design (Option 1), full with joists shown (above), and in cross section (below)

Figure 39. Through-joist connector prototype.

Through-joist connector - Design Logic and Description

The connecting rod is an M12 threaded rod attached to the joists via 5mm steel brackets (rigid connection one end and resilient connection the other end).
Axial resilient connection is via blue resilient foam pads (12.5mm Sylomer SR850 urethane foam – similar to rubber with Shore A value of 75 - static E is 7.2MPa, and dynamic E is 11.1MPa) acting through two washers of different areas, providing a two-stage resilience. The first washer is 2mm thick and has an area 530mm^2, the second washer is 5mm steel and has an area 3500 mm^2. The washers need to be tensioned to depress the 2mm thick first washer into the foam by 1mm.
The first washer area is calculated to provide a dynamic spring constant of 469 kN/m.
A further 2mm of axial displacement (1mm on washer 1 and 1mm into washer 2) will give a load transfer of 3.9kN.

Shear resilient connection is via the black neoprene bushes with a wall thickness of 4mm inside the steel tubes in the joists. To transfer shear forces and isolate the connecting threaded bolt we rigidly connect one end of the bolt and resiliently isolate the other end through a neoprene sleeve (Mason HLB 13mm ID 13mm (OD 22mm)).
In the Through-joist Connector design the sleeve has a projected area onto rod of 12mmx90mm for an M12 threaded rod.
The thread of the rod is 1mm deep and we get a 0.5mm clearance for 13mm ID sleeve (wall thickness 4.5mm), after 2mm of lateral movement we get 1mm average compression of sleeve (half 1.5mm half 0.5mm due to thread depth). For neoprene rubber durometer shore value 50, E=3MPa , stiffness = 3x12x90/0.0045 = 720,000 N/m. Or 720N load transfer after 2mm movement. This may be too little for what we want, but it could prove to be greater load transfer than this if the rubber is sufficiently constrained.

Screw connectors on each bracket were 6 of Type 17 g14 75mm long with 45mm of thread. This should achieve the required ULS load of 20kN.

Across-plate connector

This connection system is screwed to bottom plates and spans the double stud gap. The SLS design aim is 800N load transfer with 2mm displacement both tension/compression and in shear. The ULS design aim is 4kN with 10mm displacement both tension/compression and in shear.

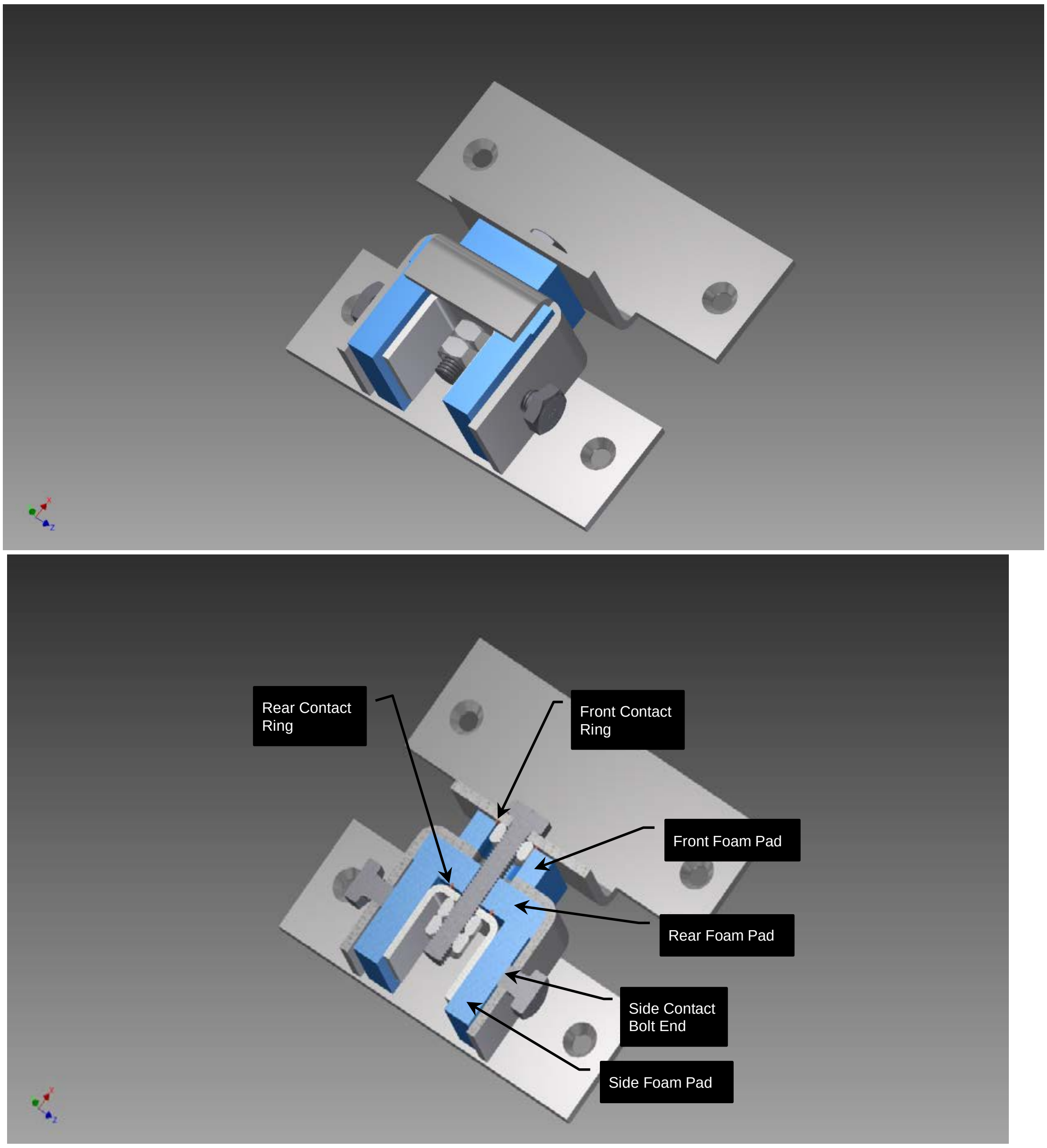


Figure 40. Across-plate connector design, complete perspective view (above), and in cross section (below)

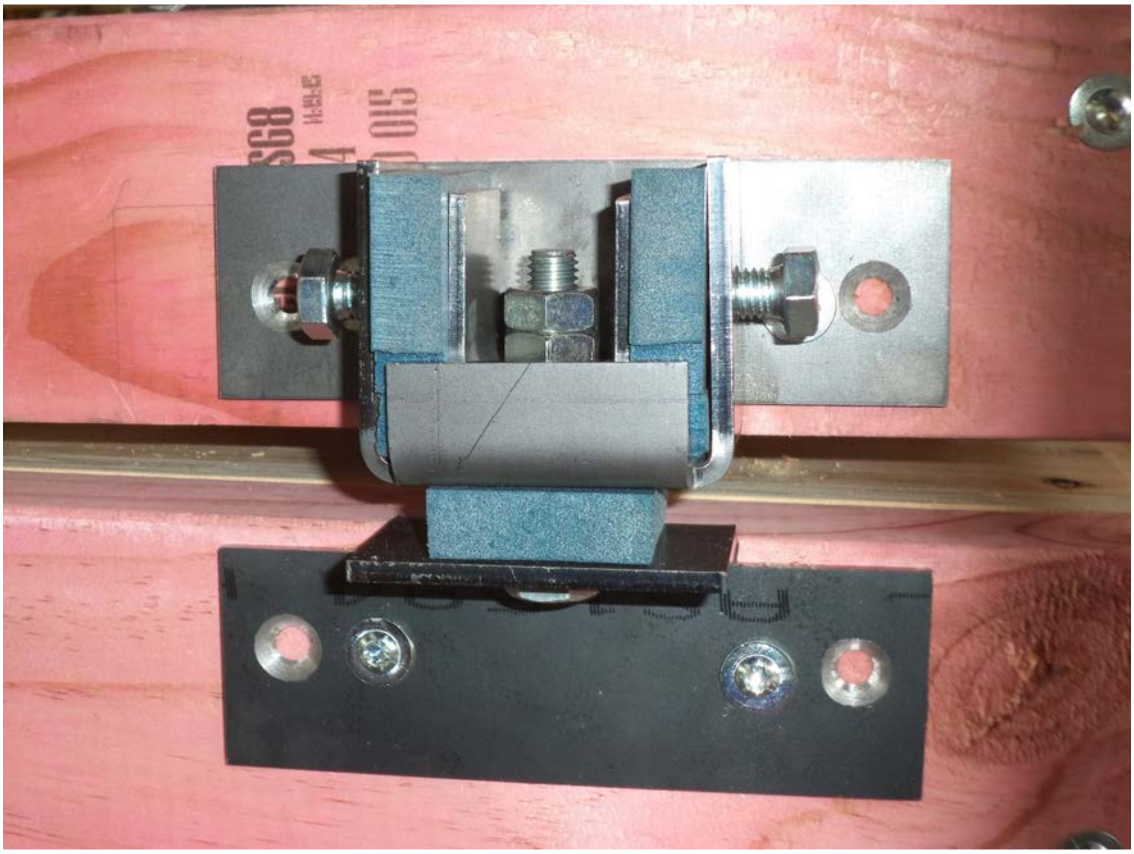


Figure 41. Across-plate connector design prototype as screwed on to bottom plates. Screw holes were redrilled to fit a slightly different screw head from that initially anticipated.

Across-plate connector – Design Logic and Description

The system is designed to be screwed to the bottom plates and joists of a double-stud wall system, spanning across the gap between the two bottom plates. The connection is via an M10 bolt with a rigid connection one side and resilient connection the other side.
The brackets are made from 4mm folded steel
Axial resilient connection is via blue resilient (front and rear) foam pads (12.5mm Sylomer SR850 urethane foam – similar to rubber with Shore A value of 75 - static E is 7.2MPa, and dynamic E is 11.1MPa) acting through 1mm thick and 2mm deep contact rings (denoted Front and Rear in Figure 7), providing the first, high-resilience stage of a two-stage resilience, with the steel brackets providing the second stage. The M10 bolt needs to be tensioned to depress the 2mm thick rings into the foam by 1mm.
It was calculated that the rings provide a dynamic spring constant of 117 kN/m.
A further 2mm of axial displacement (1mm on ring and 1mm into bracket face) will give a load transfer of 850N.

Shear resilient connection (horizontal) is via the side foam pads and bracket flanges. To transfer shear forces and isolate the connecting M10 threaded bolt we rigidly connect one end of the bolt to the bracket and resiliently isolate the other end through the blue urethane foam pads.
First stage resilience is provided through the contact area of the side M10 bolt ends, which are screwed down to depress 1mm into the foam pads. This first stage resilience is calculated to provide a dynamic spring constant of 113 kN/m.
2mm of horizontal shear displacement (1mm on bolt end and 1mm into bracket sides) will give a load transfer of 820N.

Screw connectors on each bracket were 2 of Rothoblas TBS8160 TBS LARGE HEAD SCREWS 160mm long. This should achieve the required ULS load of 4kN in shear and tension and compression, as well as transferring forces into the joist.

Acoustic Measurements

The prototype system samples were setup on timber sections and a shaker and accelerometer used to determine the dynamic spring constants of the connections in various states. Although vibration in three axes were measured, the axial vibration was primarily used to determine the spring constants.

Measurement setup

Acquisition system: 01dB 4 channel Harmonie (ICP power, 0.15Hz LF cutoff)

Vibration measurement: Use a triaxial accelerometer PCB 356A31 (SN 69930) to measure acceleration. X-axis points vertical down. Y points horizontal in line with joist run, Z points horizontal perpendicular to joist run.
X – Channel 1, Y – channel 2, Z – channel 3.

Excitation: Ling (LDS) shaker V406, instrumented with an Endevco force transducer 2311-10 (SN 3484). Force transfer through stinger.
Signal is Pink Noise.
Force- channel 4

Samples set on resilient pads to isolate from concrete floor (12.5mm sylomer each end of joist sample)

Through-joist connector design

Samples setup on 90x20mm resilient pads (12.5mm sylomer each end of joist sample)

Sample mass is 4.1kg for non-resilient side, 4.4kg for resilient side.

Measurements
Excitation directions:

- y-direction (transverse) on non-resilient side of connector, end of joist segment
- z-direction (axial) on non-resilient side of connector, end M12 rod.

Measurement points:

- Non-resilient side, on joist near threaded rod entry point
- Resilient side, on joist near threaded rod entry point

System states:

1. Rubber sleeve on resilient side connected only (Sylomer pads removed)
2. Sylomer pads connected only, (Rubber sleeve on resilient side removed).
3. Complete, full system
4. Nuts on 70mm washers tightened so that both 70mm washers firmly contacts sylomer. (labelled 70mm washer)
5. No connection to threaded rod (background vibration transfer)
6. Direct rigid connection, where one steel disc hard contacts steel bracket on resilient side.

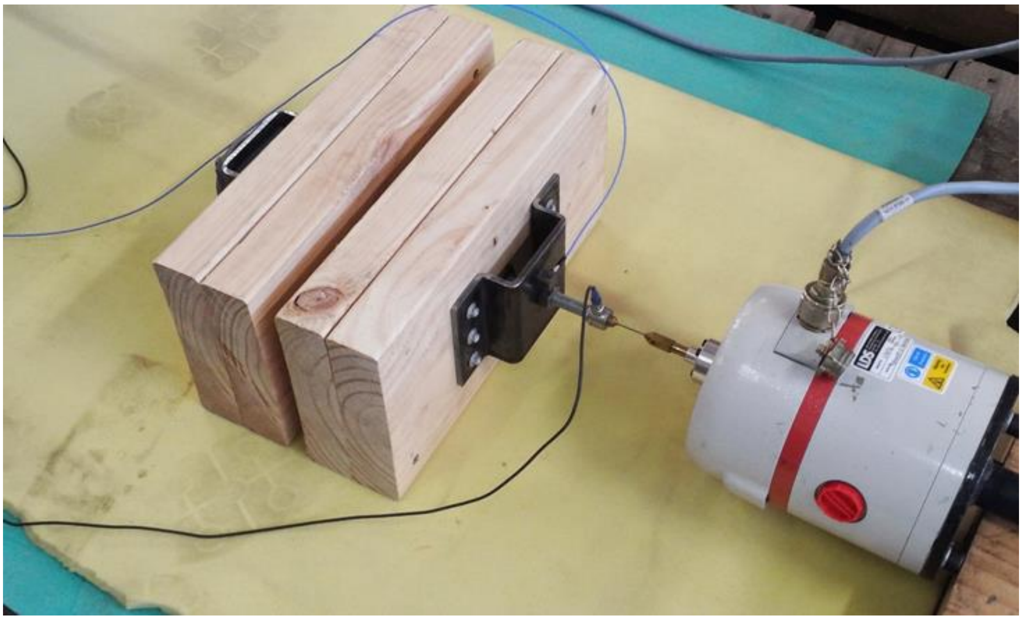


Figure 42. Through-joist connector vibration measurements

Results

Table 1. Through-joist connector dynamic stiffness results

		Axial resonance (Hz)	Dynamic Stiffness (N/m)
1	Rubber sleeve only	56	262756.5
2	Sylomer only 34mm washer	97	788353.2
3	**Full system 34mm diam Area 1 washer**	**123**	**1267615.6**
4	Full compressed to both 70mm washers	257	5534056.5
5	No connection (support mount)	22	40553.0
6	Rigid connection (on resilient side)	422	14921148.3

Comments

The first stage (normal operation) dynamic stiffness of the full system (yellow highlighted row in Table 1) is almost 3 times the design stiffness of one foam pad because of the combined effect of 2 axial pads connections and the rubber sleeve. This gives an expected loss of acoustic performance of 1dB for low frequencies for a connector every 3m.

To simulate a situation when the system is compressed beyond the first stage of low stiffness into the second stage (70mm washer) of larger area, the nuts were tightened to compress the foam onto the 70mm washers. The second stage (abnormal operation) dynamic stiffness of the full system (green highlighted row in Table 1) is over 4 times the design of one foam pad because of the combined effect of the 2 axial pads. In practice, only one foam pad will be engaged, which would halve the stiffness of that measured. This gives an expected loss of acoustic performance of 3dB for low frequencies for a connector every 3m.

Across-plate connector design

Sample consists of Option 4 screwed to bottom plate section (90x45x180mm) with 45mm T17 screws.

Samples setup on 20x20mm resilient pads (25mm sylomer each end of bottom plate sample)

Sample mass (with wood) is 0.93kg for non-resilient side, 0.92kg for resilient side.

Measurements
Excitation directions:

- y-direction (transverse) on non-resilient side of connector, side of M10 nut at end of M10 bolt
- z-direction (axial) on non-resilient side of connector, end M10 bolt (with nut on end).

Measurement points:

- Non-resilient side, on steel plate just above M10 bolt hole.
- Resilient side, on end of M10 bolt

System states:

1. Complete, full system
2. Nuts tightened so that both brackets washers firmly contacts 40x40mm front sylomer (not going through rings) (tight)
3. Front Sylomer pads connected only, (Side sylomer pads removed).
4. Side sylomer pads connected only (Front Sylomer pads removed)

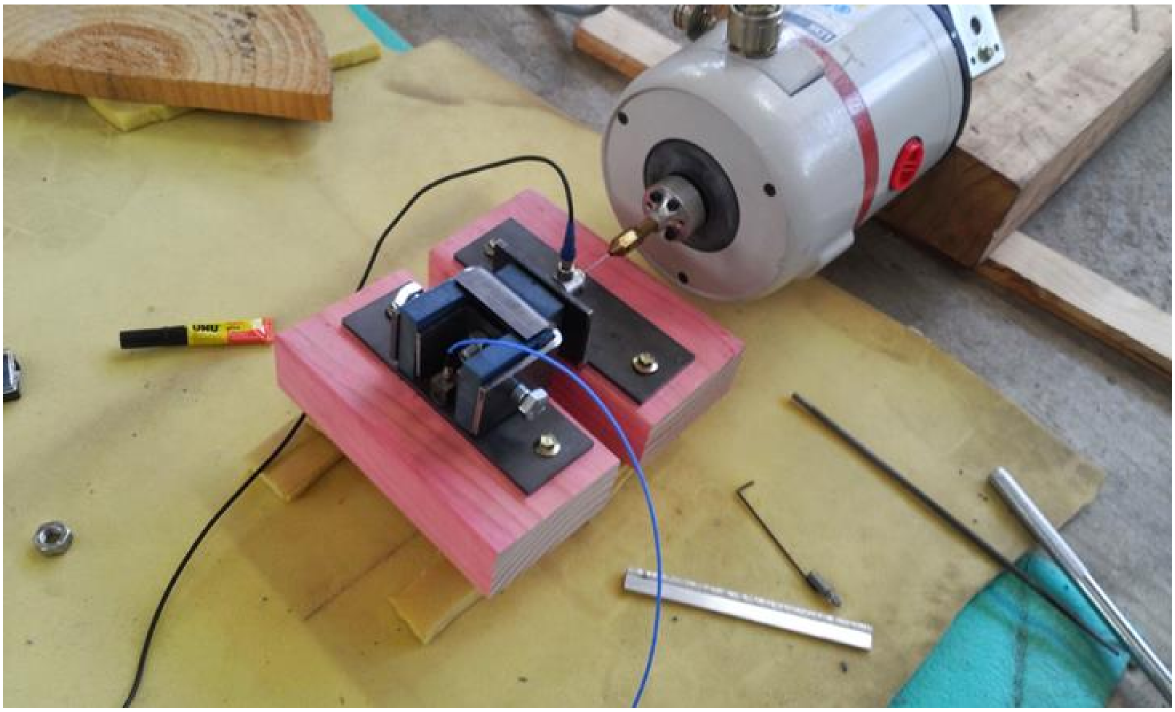


Figure 43. Across-plate connector vibration measurement

Results

Table 2. Across-plate connector design dynamic stiffness results

		Axial resonance (Hz)	Dynamic Stiffness (N/m)
1	Full system with 22mm 1mm wide rings	178	578493.9
2	Full compressed to bottom out rings	269	1321184.1
3	Only front sylomer (no side sylomer)	144	378602.8
4	Only side sylomer (no front sylomer)	89	144623.5

Comments

The first stage (normal operation) dynamic stiffness of the full system (yellow highlighted row in Table 2) is over 5 times the design of one foam pad because of the combined effect of 2 axial pads connections, the side pads, and the fact that the 1mm wide rings compress more area than naively expected (due to the coupled nature of the foam). This dynamic stiffness gives an expected loss of acoustic performance of 3dB for low frequencies for a connector every 600mm.

To simulate a situation when the system is compressed beyond the first stage of low stiffness into the second stage (full area of front and rear foam pads) of larger area, the nuts were tightened to compress the foam onto the front faces of the brackets. The second stage (abnormal operation) dynamic stiffness of the full system (green highlighted row in Table 2) is about 2 times the design of one foam pad because of the combined effect of the 2 axial pads. In practice, only one foam pad will be engaged, which would halve the stiffness of that measured. This gives an expected loss of acoustic performance of 4dB for low frequencies for a connector every 600mm. Which is almost the same as when stage one is engaged.

The other results give an indication of what is happening with the isolated parts of the connector.

Structural Measurements

The tests were conducted to simulate an earthquake sequences by adopting the "Earthquake test procedure" loading sequences proposed within the "BRANZ Evaluation Method No 1 (1999) for Structural Joints - Strength and Stiffness Evaluation".

Loads were applied to the four specimens to achieve the following increasing sequence of displacements: ±2mm, ±4mm, ±9mm, ±12mm, ±15mm, ±20mm. The displacement values were reached in cycles of 3 repetitions per displacement until the sequence of cycles end (±20mm reached 3 times) or depending on specimens' behaviour (unsustainable deformation).

A Wiedemann Universal Testing Machine was used to apply the displacements to the specimens.
Displacements have been collected using a ±25mm Linear Variable Deflection Transducer (LVDT) and data logged directly from the test machine with 5 readings per second from the Data Logger.
The outputs from the Data Logger have been copied into Microsoft Excel to generate the Load Deflection Plots.

Tests were done for both, axial tension/compression as well as shear.

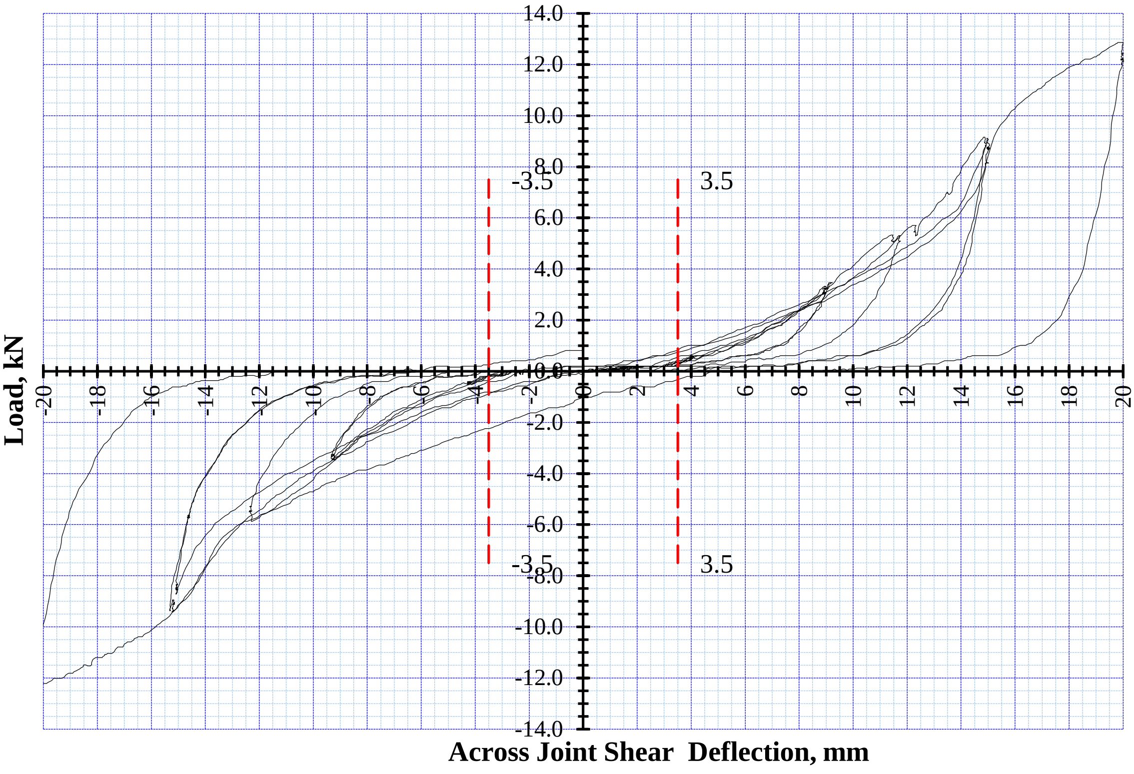
Figure 44. Through-joist connector shear load test.

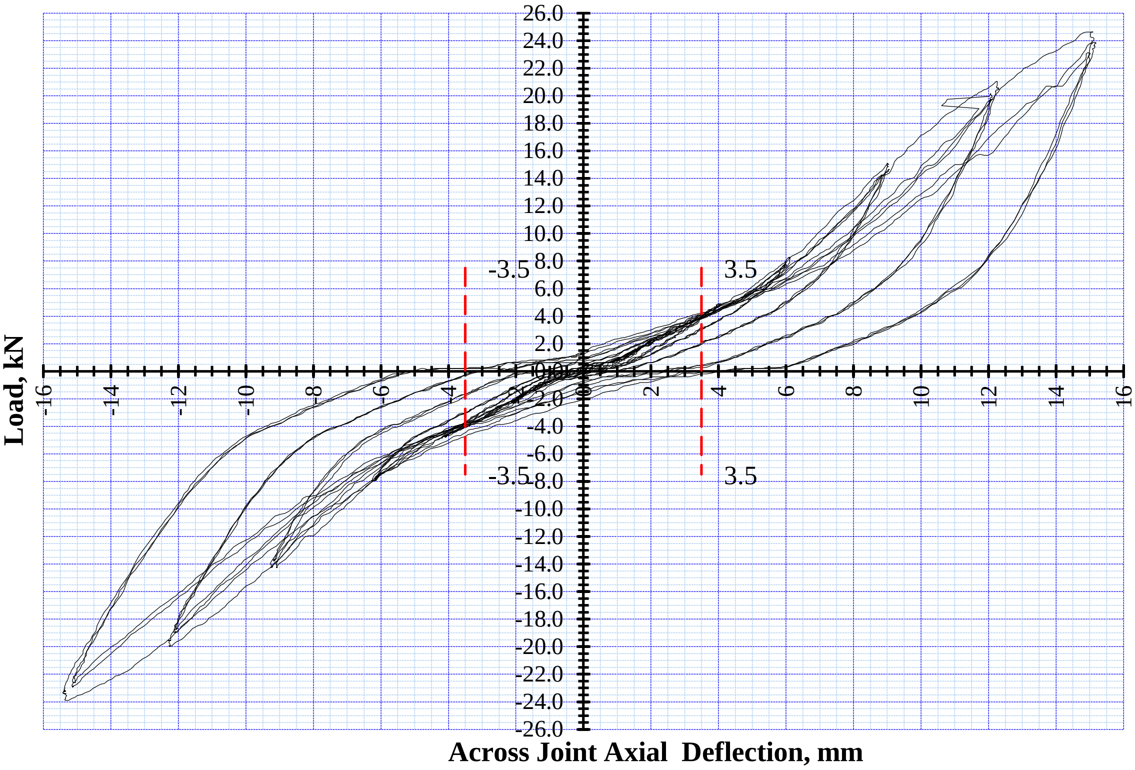
Figure 45. Through-joist connector axial load test

Figure 46. Across-plate connector shear load test.

Figure 47. Across-plate connector axial load test.

Through-joist connector results



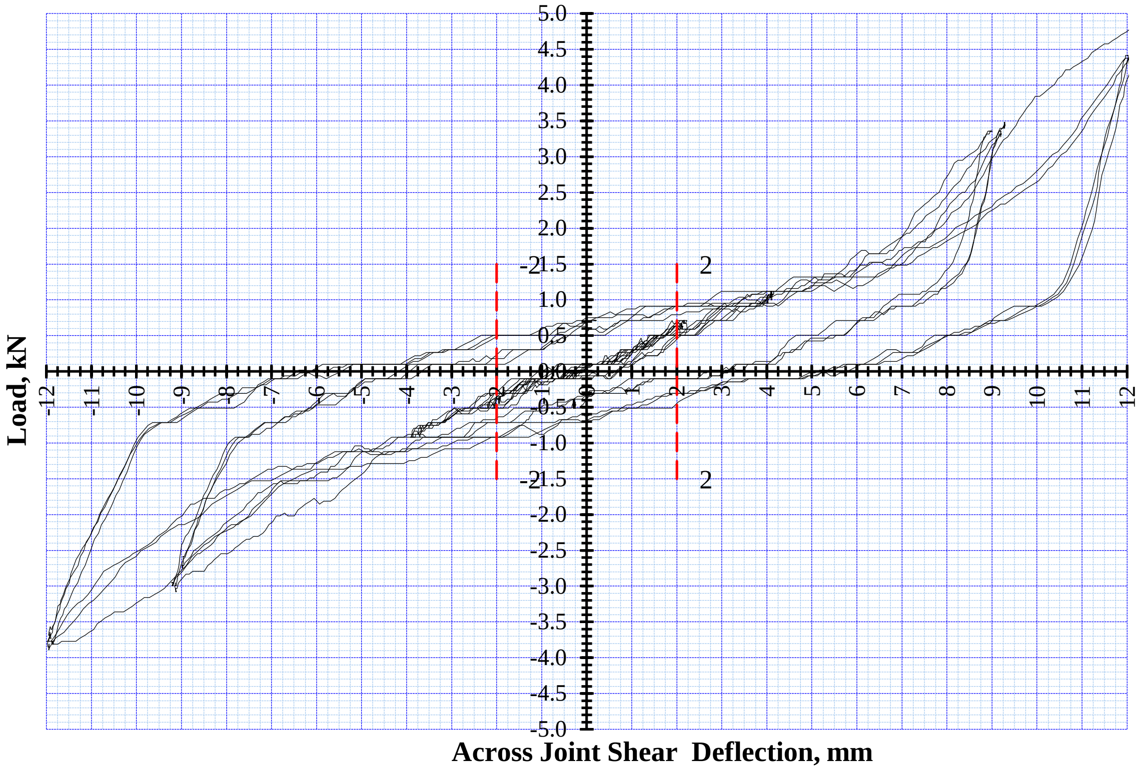


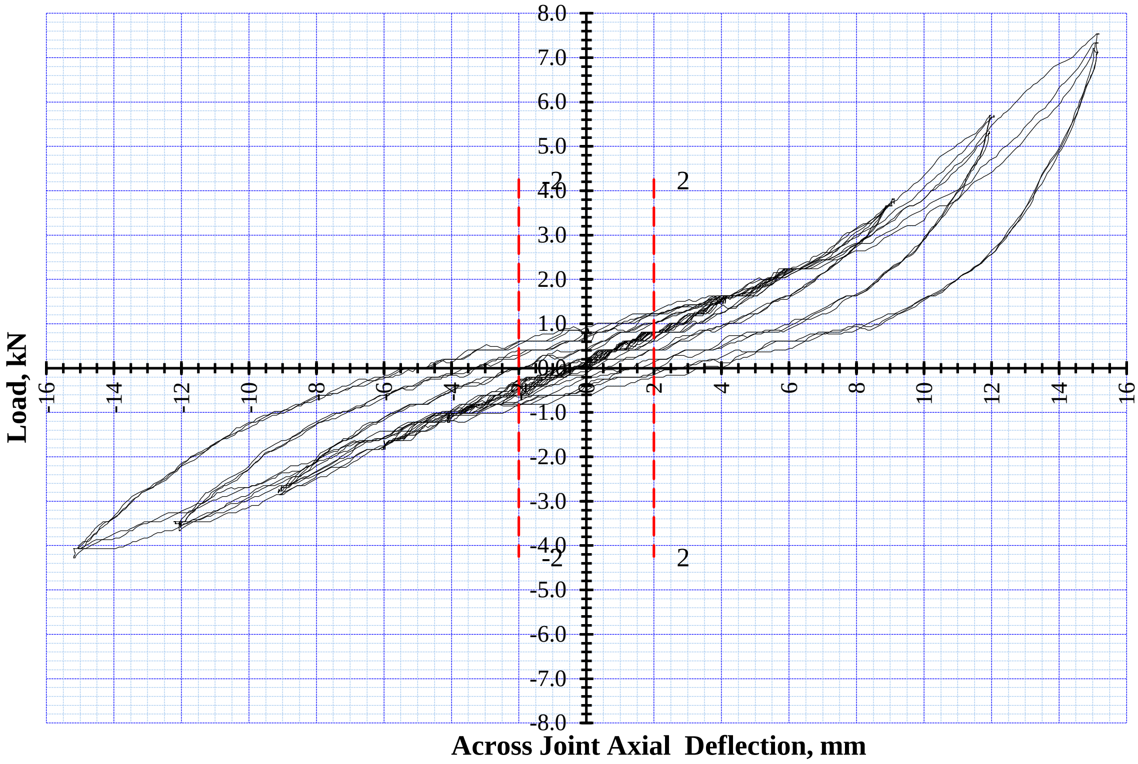
Comments

- No screw pull-out observed.
- Some flexure of 5mm steel plate brackets, but no permanent damage
- M12 threaded rod distorted badly in shear, and permanently bent. Also had distortion of steel tubes.

Figure 48. Distortion of M12 threaded rod

Across-plate connector Results





Comments

- No screw pull-out observed, but a little bending of screws in shear and hence slip of brackets.
- Flexure of 4mm steel plate brackets, and permanent deformation

Figure 49. Distortion of brackets under axial compression load (about 6kN)

Figure 50. Final distortion of brackets after axial compression/tension test.

Conclusion and Development Suggestions for the preliminary designs

Conclusion

- The Through-joist connector design (Option 1) showed good dynamic stiffness performance (1dB low-frequency transmission loss performance reduction for 3m spacing), and good tension compression load transfer, but poor shear load transfer (although in part it wasn't unexpected).

- Design Across-plate connector design (Option 4) showed poorer than expected dynamic stiffness performance (3dB low-frequency transmission loss performance reduction for 600mm spacing) due to the effect of side foam pads and foam coupling, but good tension/compression load transfer, and good shear load transfer.

Suggestions

- Change Through-joist connector design to consist of four M12 or M16 bolts, keep total surface area of foam pad the same (or go to a softer pad).

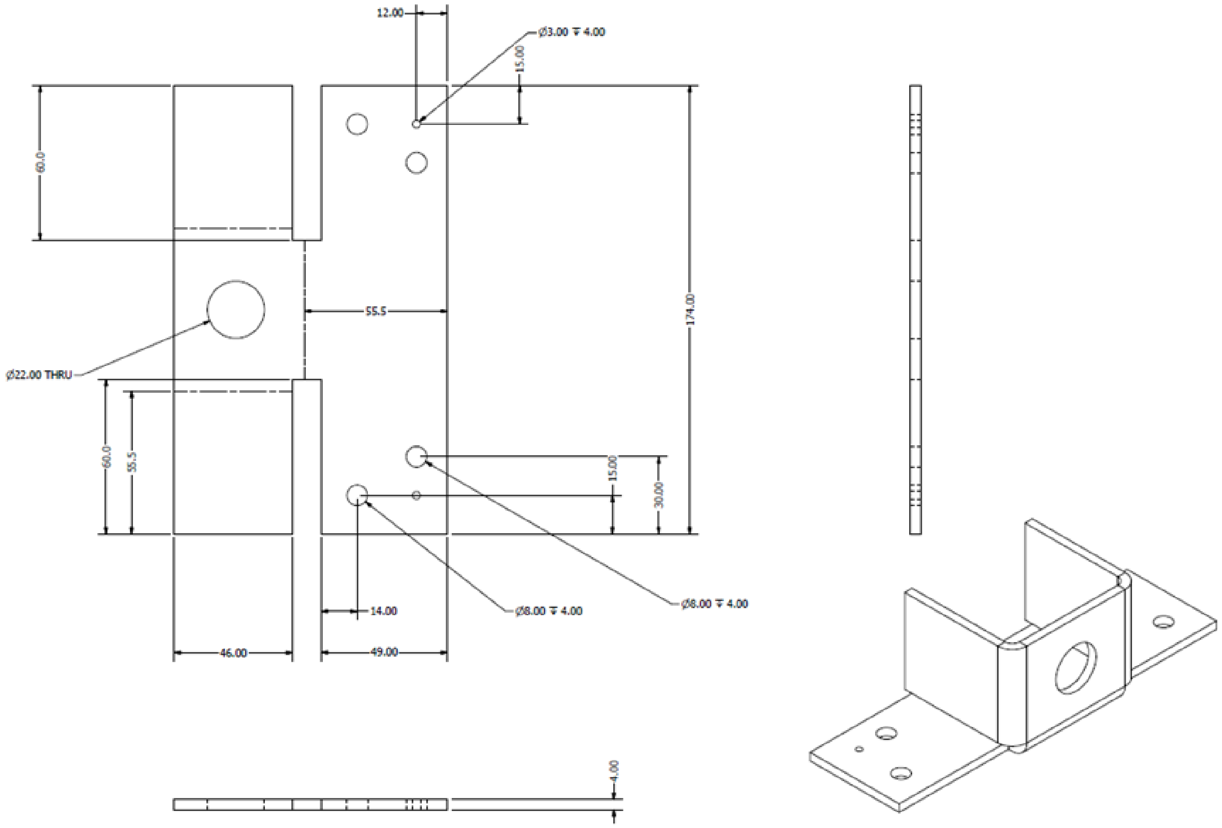
- Change Across-plate connector stage 1 contact area to points in an attempt to reduce axial stiffness, or only use side contact points only for stage 1 coupling, and ditch rings (which would give me desired stiffness coupling).

- Develop a new option, another Across-plate connector design, which has increased load transfer, and is also screwed on to the bottom plate.

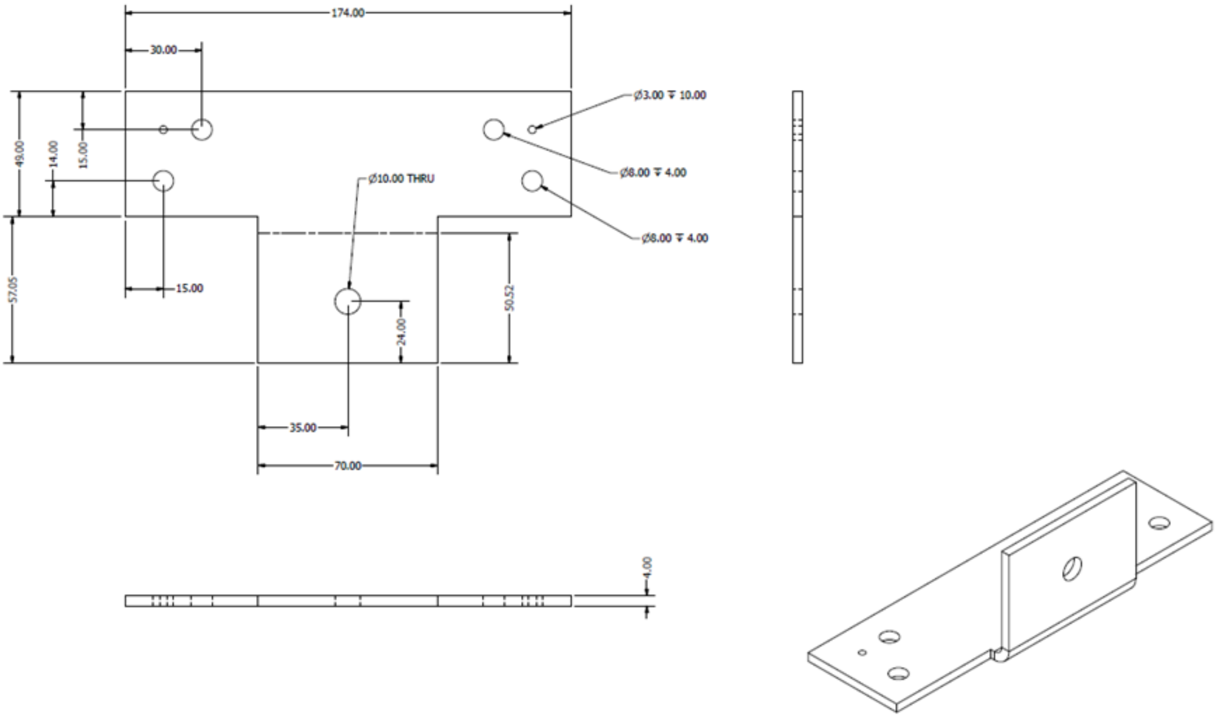
- Would prefer to focus on one design, rather than carrying through two designs.

Appendix D: Connector Drawings

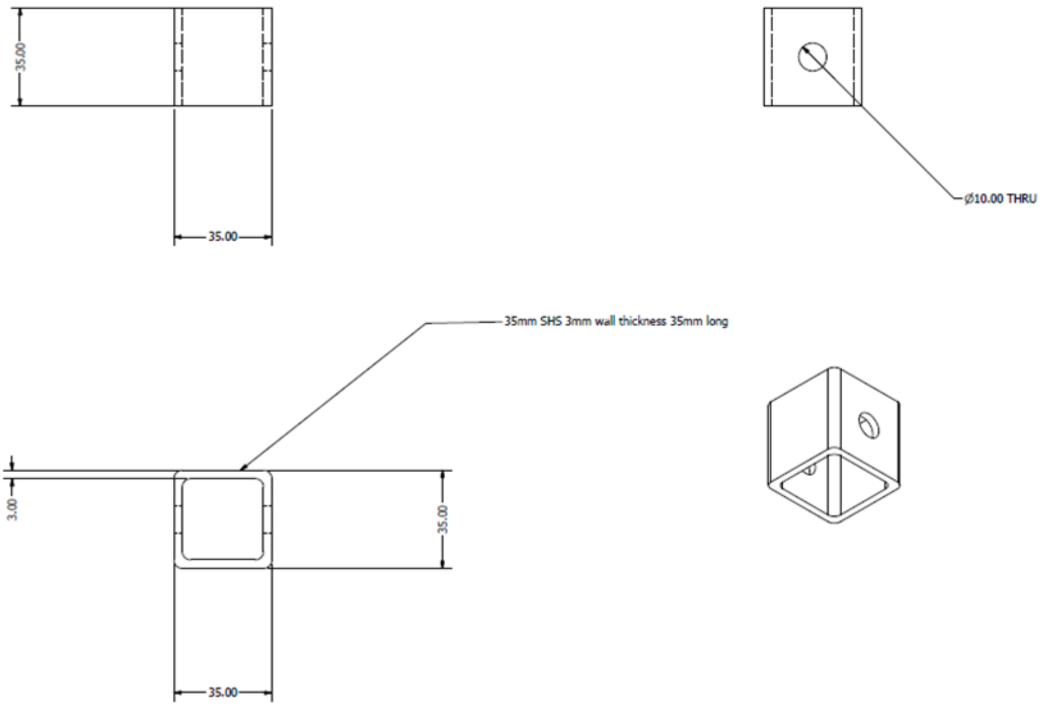
Cup bracket



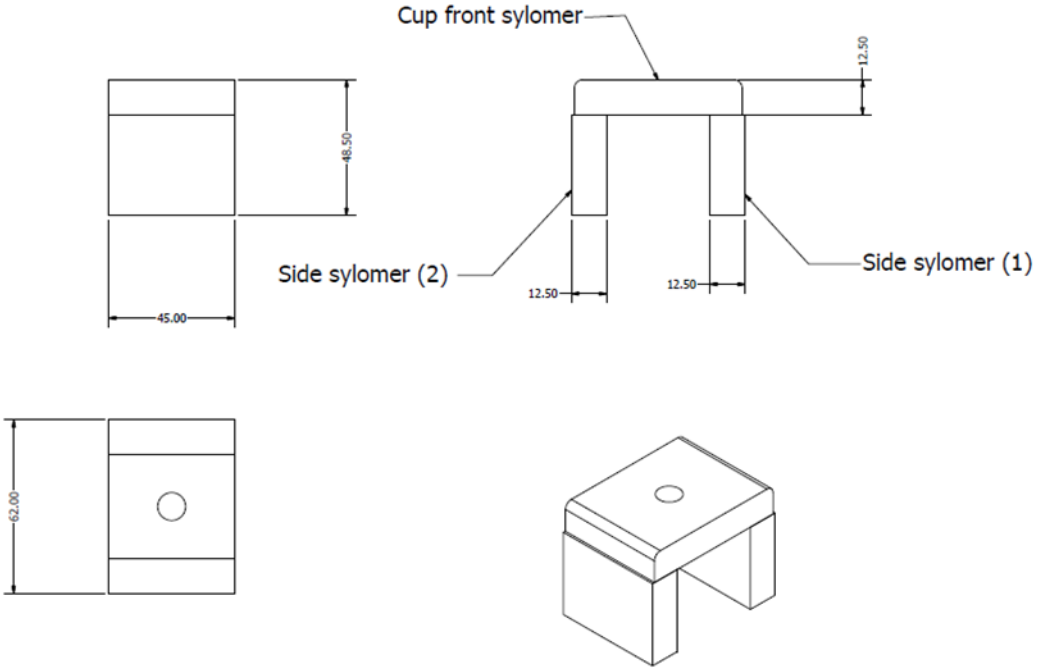
L-bracket



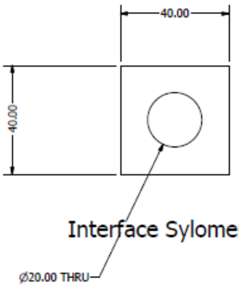
Square Hollow Section Insert



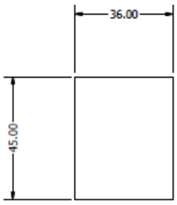
U-shape Sylomer



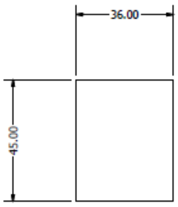
Sylomer foam dimensions



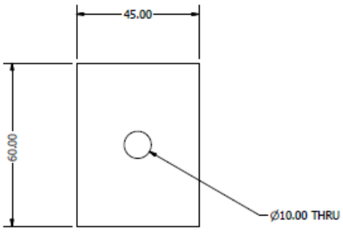
Interface Sylomer



Side sylomer, left

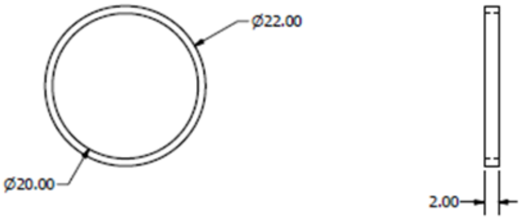


Side sylomer, right



Cup front sylomer

20mm Ring



First Stage Contact Ring

Acknowledgements

The team would like to thank Bruce Davy from Scion for assisting with the structural testing of the specimens, and Jamie Agnew for building the test wall at Auckland University.
Also Getzner and Pyrotek for donating test specimens of Sylomer.

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