An Acoustically Isolating Timber Frame Connection System

Grant Emms[1]*, Andrea Stocchero[1], Doug Gaunt[1], Warwick Banks[2], Dan Scheibmair[3], Keith Ballagh[4] and In Ling Ng[5].

[1]Scion, Private Bag 3020, Rotorua, New Zealand.
**Contact e-mail: grant.emms@scionresearch.com*
[2] Knowles Consulting Ltd, Level 3, 5-7 Kingdon Street, Newmarket, Auckland, New Zealand
[3]Pryda, 8 Orbit Drive, Albany, Auckland, New Zealand
[4]Marshall Day Acoustics, 84 Symonds St., Auckland, New Zealand.
[5]MiTek NZ, 40 Neales Road, East Tamaki, New Zealand

ABSTRACT

A connection system was developed to provide structural load transfer between multi-residential units without compromising acoustic performance. The primary application of the system is to connect the frames of double-stud inter-tenancy walls found in terraced housing, transferring horizontal seismic and wind loads. Such a connection system makes available more options for designers, enabling taller light-framed systems to be built with fewer design compromises.

The connectors were designed to have a high degree of structural connection when a building is under extreme external loads from seismic events or extreme wind events. Under normal conditions, however, the connectors provide less structural connection, giving better acoustic isolation between units. This paper examines the design of the connectors, and presents the acoustic and structural performance test results.

1. INTRODUCTION

Double-stud inter-tenancy wall systems provide good acoustic isolation performance between units. An effective double-stud system consists of two frames that are not rigidly connected. However, this structural disconnection between units means that each unit requires a lot of structural bracing to maintain the gap between each unit when under seismic or wind load. It can be difficult to design sufficient bracing to meet these structural performance requirements. Transferring axial and shear loads between individual unit floor diaphragms is a means by which the amount of bracing required in each individual unit can be reduced.

A new structural connection system which provided the needed structural connection between light-framed timber multi-residential units, without significantly compromising the acoustic performance, was developed by a team of New Zealand building industry professionals and companies. The project was part funded by the Building Levy, and lead by the built environment team at Scion

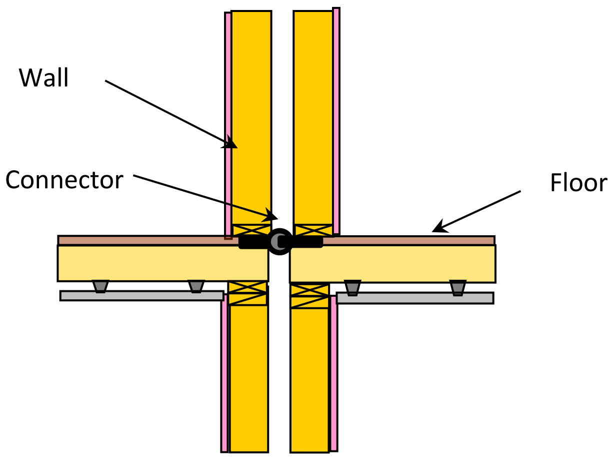

Figure 1: Cross section of an inter-tenancy double-stud wall showing the connector location.

2. DESIGN REQUIREMENTS

2.1 Structural Requirements - Seismic design

When two buildings are located close to each other, they may hit each other during strong seismic events and cause damage. This effect is called pounding. Theoretically, if the two buildings have exactly the same characteristics, then under the same seismic motions they should move together, in phase, without hitting each other, in the same way that wind-screen wipers on a car move together (MacRae, Clifton, & Megget, August 2011). However, buildings seldom have the same characteristics and experience the same seismic forces, so may not move in phase.

Pounding may be guaranteed to not occur during a design level earthquake if the distance between the buildings or building sections is greater than the sum of the maximum displacements of each building alone. 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.

In common terraced house design and construction practice the gap between building units (commonly 20mm) does not guarantee the avoidance of pounding. Furthermore, many terraced houses do not have any bracing walls at all towards one end of the building, which would otherwise mitigate the structural displacement occurring under seismic and wind stress.

Structural connection systems at floor level provide the needed structural connection be-tween light timber-framed timber multi-residential units to transfer lateral forces to the floor diaphragms.

2.1.1 Connection force transfer requirements

The connections need to work at two levels of force transfer: the Serviceability Limit State (SLS) where the connection will return to normal undamaged, and at Ultimate Limit States (ULS), where the connection is damaged but is still able to hold (Beattie, Buchannan, Gaunt, & Soja, 2001).

The designs are predominantly governed by seismic forces at elastic load levels. The forces at SLS are around 20% of those at ULS. For example if one requires 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.

Connections need to have relatively little movement; up to around 2mm movement for the Serviceability Limit State and 10mm maximum movement in any direction at ULS.

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 level 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.

2.2 Acoustic Performance Requirements

To achieve good acoustic performance, we require any structural connector to not significantly increase 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 – a change in acoustic performance which would not be noticeable by most people.

In general, due to the double skin and low mass nature of a timber-frame wall system, the acoustic insulation is poorest in the low-frequency region. In the low-frequency region the acoustic performance of a double stud wall system is governed by the air stiffness of the air gap between the layers and 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)

$$R = 20\log_{10}\left(\frac{2\rho s'/k}{(2\pi f)^2 m_1 m_2}\right). \quad (1)$$

s' is the stiffness per unit area of the air (and other resilient connections) between the wall leaves. The wall leaves have surface masses m_1 and m_2. The frequency of the sound is given by f, the wavenumber by k, and 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. Therefore, the single figure ratings such as STC and R_w tend to be controlled more by the low-frequency performance.

We can see from Eq. 1 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

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

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 722,500 N/m/m2, and hence the stiffness per unit area of any additional connections must be less than 87,000 N/m/m2.

If we have a maximum number of ties every 0.6m along the wall (as suggested by structural calculations which) for a wall height of 2.8m, we would find that each tie would need to have less than 143 kN/m of stiffness.

These are very simple prediction calculations which only offer crude predictions at low frequencies. For the purposes of this calculation we have also ignored the effect of any infill, which can change the effective density and speed of sound in the cavity. Generally we would expect such infill effects to be relatively small at low frequencies (Chung, 2014). Measurements were carried out to obtain the full frequency performance in a real wall.

3. CONNECTOR DESIGN

After performing testing on some initial concept connector designs, a final connector prototype design was developed. The connector spans the gap across the bottom plates of the double stud wall, and works by minimising the rigidity of the connection from one side of the connector to the other, whilst maximising the load transfer in both axial and shear directions. It is attached to the floor diaphragm by four 160mm long self-tapping wood screws, which penetrate through the bottom plate and flooring sheet into the edge joists, providing excellent structural connection to the floor diaphragm.

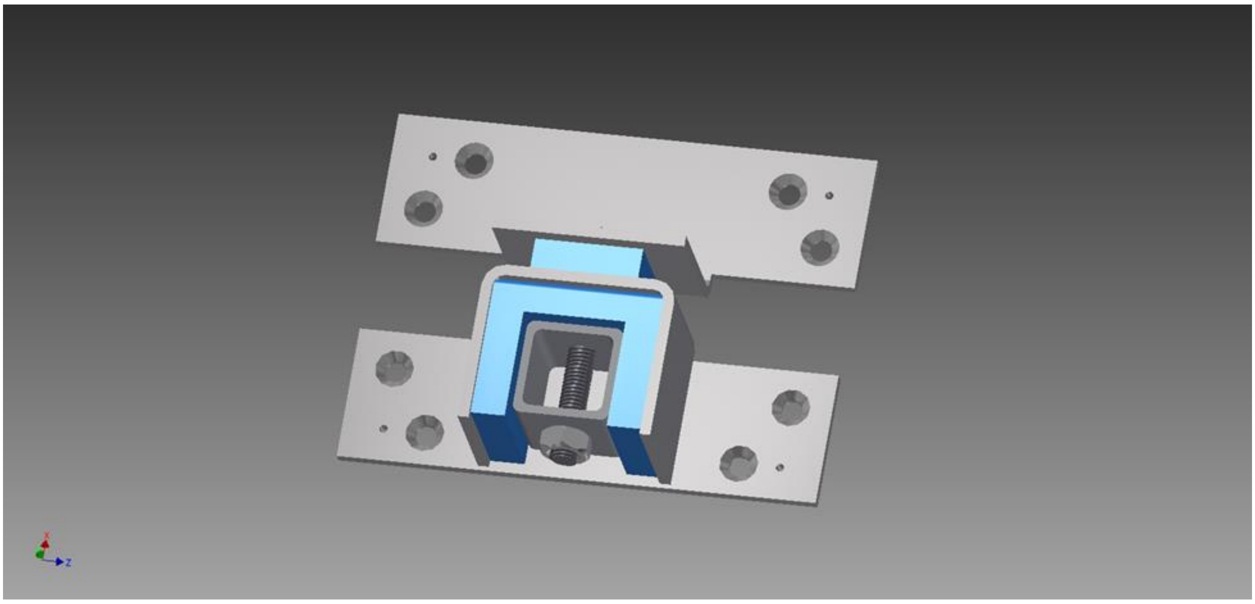

Figure 2: The structural / acoustic connector design showing mild steel parts in grey and Sylomer SR 850 urethane foam isolation pads in blue.

4. STRUCTURAL PERFORMANCE MEASUREMENTS

Tests were conducted at Scion to simulate 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". Results of these tests enabled load-displacement curves to be plotted for shear and axial loads applied to the connectors. Each connector has an average shear and axial load transfer of 500N at displacements of 2mm (assumed Serviceability Limit State), and a minimum of 2100N of axial and shear load transfer at displacements of 10mm (assumed Ultimate Limit State).

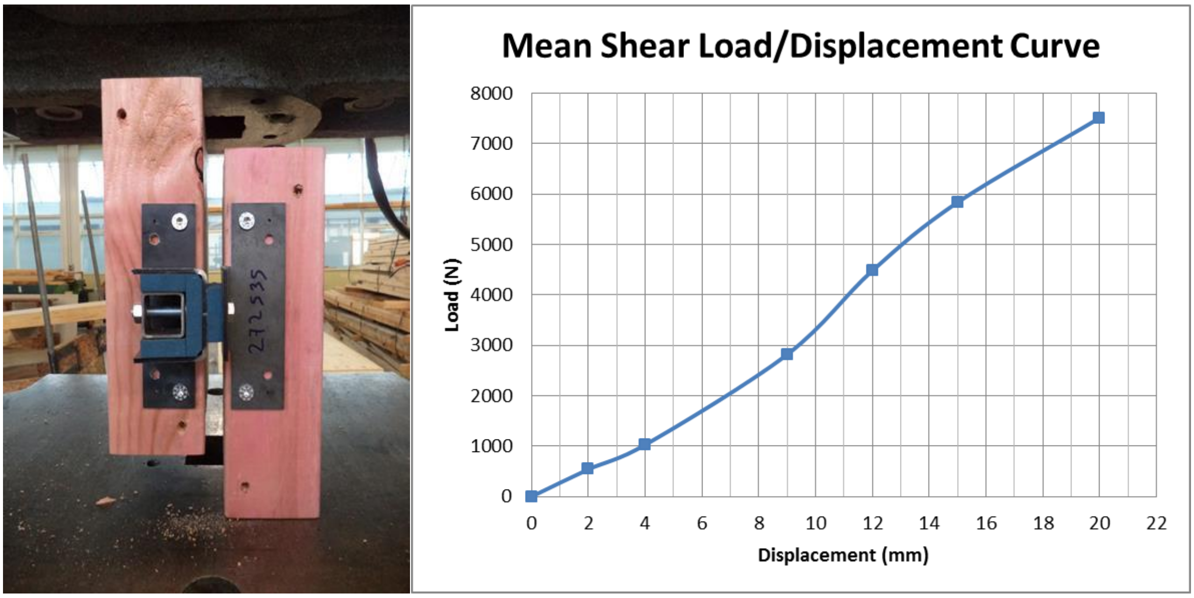

Figure 3: Average load deflection curve for shear cyclic test of three specimens. This is the average of shear response in both directions.

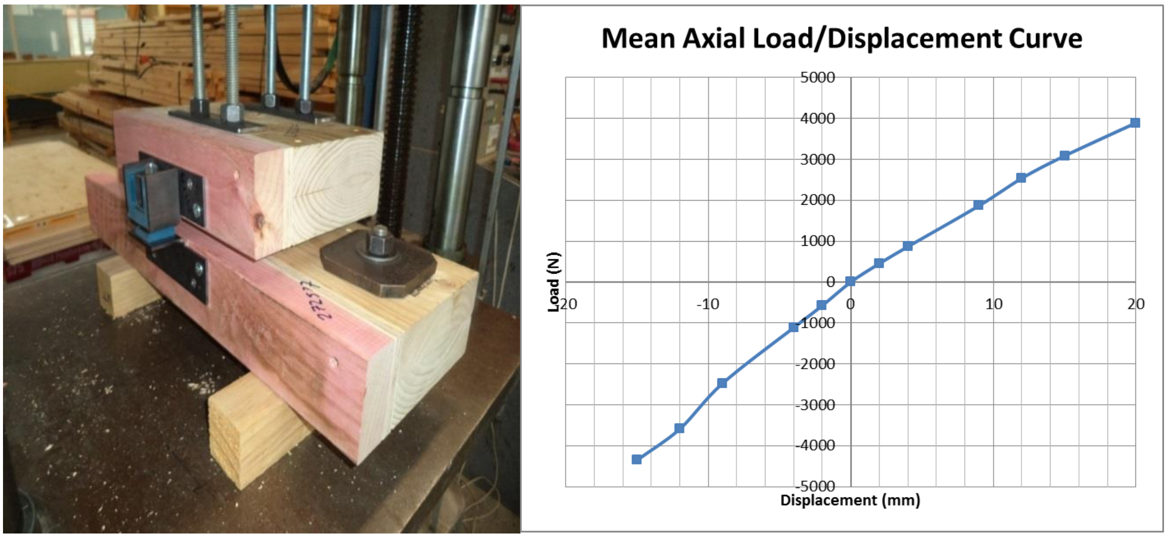

Figure 4: Average load deflection curve for axial cyclic loading test of three specimens. Negative displacement and load corresponds to compression and positive displacement corresponds to tension.

5. ACOUSTIC TRANSMISSION LOSS MEASUREMENTS

Full-scale acoustic transmission loss wall measurements were performed at Auckland University's Acoustic Test Laboratories in accordance to ISO 10140-2.

The wall consisted of a double-stud frame sitting on edge joists. The top plate and edge joists were screwed to the chamber aperture collar. The bottom plates were screwed to the edge joists. The ends of the joists were screwed to the sides of the chamber collar. Importantly, the joists were not screwed down at the bottom, allowing the joists to vibrate freely. The bottom edge of the joist was only sealed with a mastic sealant bead to stop sound from penetrating through any air gaps. The joists were covered with a secondary plasterboard boxing to reduce sound penetration through the acoustically weaker joists. The double stud frames were vibration isolated from each other. The walls were infilled with one layer of polyester batts and were lined with two layers of 13mm fire-rated plasterboard (Figure 5).

A connector was mounted every stud spacing (600mm) which is the maximum expected density of connectors for extreme structural load transfer. The acoustic test results (Figure 6) showed that the connectors reduced the acoustic isolation ratings of the wall by a maximum of 1dB (i.e. Rw = 61dB, STC = 62 dB), an insignificant amount which is not noticeable by most people.

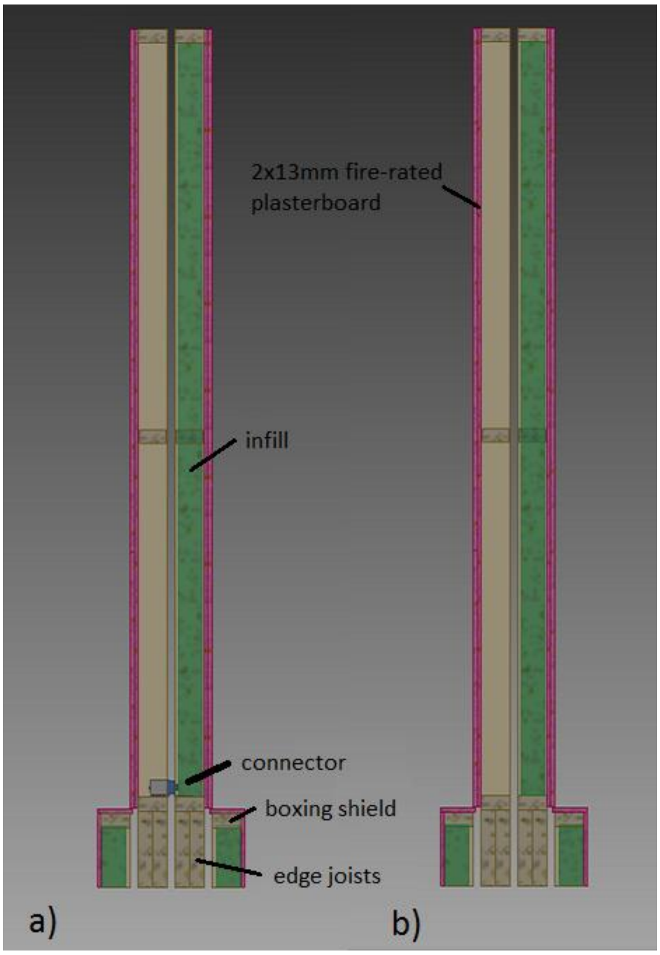

Figure 5. Cross section of the double stud acoustic test wall with (a) and without (b) the connectors. The joists were only connected to the chambers at their ends and to the wall bottom plate. The joists were not connected to the bottom of the chamber collar, allowing them to vibrate freely. Additional boxing covers the edge joists, which are acoustically weak.

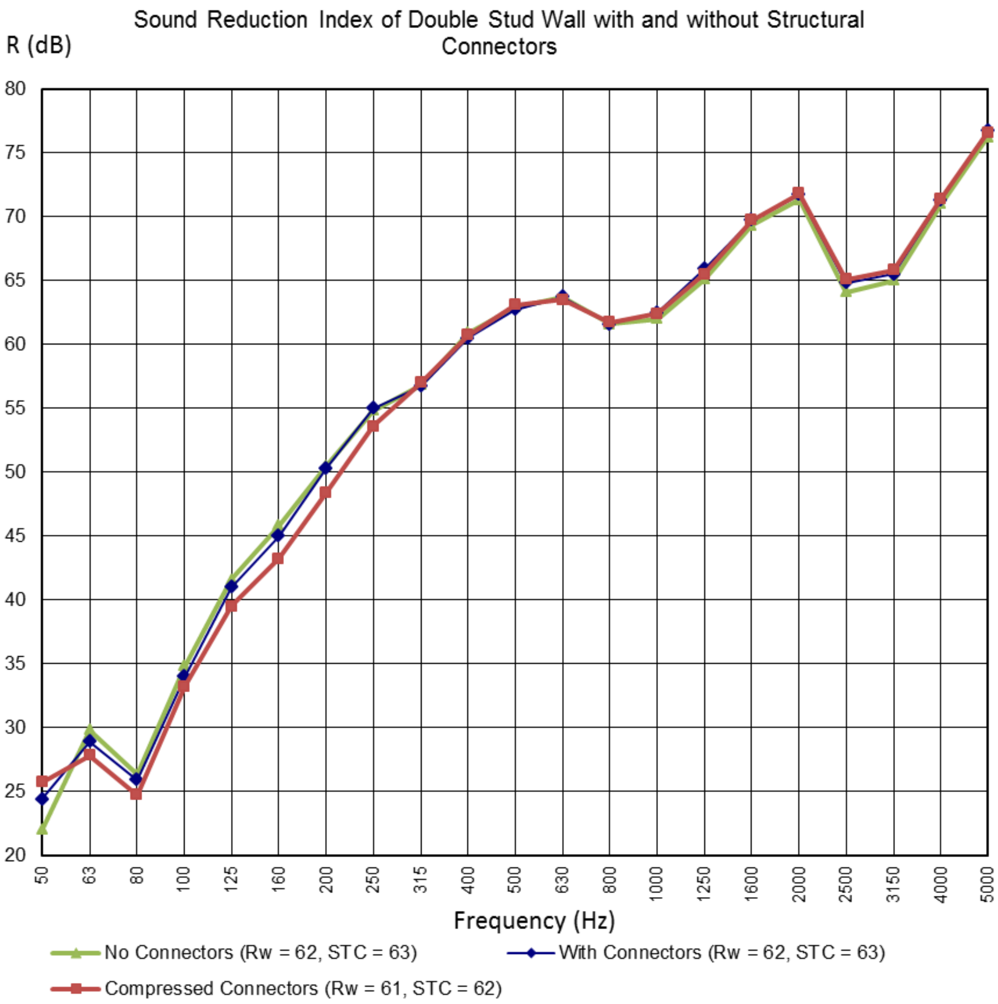

Figure 6: Sound Reduction index of a double-stud wall with and without the connectors every stud spacing.

6. CONCLUSIONS

A structural connector has been developed to connect housing units together at floor level to provide a continuous structural axial ad shear connection across double-stud walls. This allows for better seismic and wind force resistance to stop the housing units from moving too much and being damaged during earthquakes and severe storms. Dense urethane foam (Sylomer SR850) was used to provide effective acoustic and vibration isolation to prevent excessive sound transfer across inter-tenancy walls. The acoustic performance of the system was tested in the laboratory on a double-stud wall design, showing that the acoustic performance was somewhat better than predicted by a simplistic design calculation.

The design of the connectors and installation instructions are available from the project report which is on the BRANZ website (Emms, 2015). It is possible to fabricate the connectors using this information. Scion is currently working with the industry partners to develop and make available refined versions of these connectors.

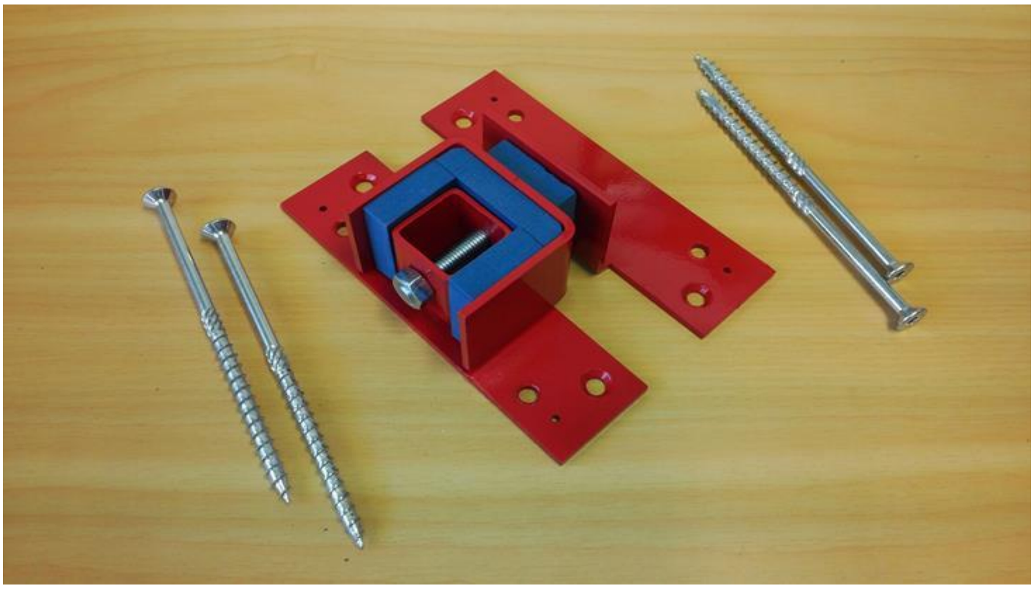

Figure 7**.** The Final connector prototype with wood screws.

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