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Study the influence of perpendicular to grain compression and creep in 4 to 8 Storey Lightweight Timber Framed Buildings

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Forest & Wood Products Australia

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Prepared for

Forest & Wood Products Australia

by

Timber Development Association

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EXECUTIVE SUMMARY

The aim of the project was to validate the assumption used within the Australian Standard AS1720.1 for calculating compression perpendicular to grain for common timber species and develop practical methods to reduce compression deformation.

The project was successful in demonstrating that perpendicular to grain displacement of wall plates by studs can be reduced. It found that stud on stud connection was the best method as it removed the wall plates out of the load path altogether. However, this study found where this is not possible, replacement of the wall plate with a stiffer timber such as a high density hardwood, softwood or cross laminated timber reduces this deformation. Very high density hardwoods and CLT were found to be the best timber to use but it is recommended that further research be conducted for the CLT wall plate system in order to understand the splitting behaviour of CLT wall plates under ultimate loads.

From the research it was found that the method to reinforce the wall plates by screws, brackets or bearing plates did not change the bearing capacity enough to justify the expenses of the fixings or labour costs to install.

The investigation also found that the method used in AS1720.1 to assign perpendicular to grain bearing capacities for various timber species by "strength group" or stress grade over predicted low to medium density timber species whilst under predicting high density timber species. Accordingly it is recommended that perpendicular to grain bearing capacity be assigned by the timber species' density and that the characteristic values of commonly used timber species be re-established.

It was also evident that AS1720.1 k7 bearing length factor was incorrect as it did not match the source characteristic value determined by AS/NZS 4063; as AS1720.1 increases the bearing capacity by 20% when it was not warranted. This led to the finding that the perpendicular to grain bearing strength check in AS1720.1 is misleading designers in what they were doing, ignoring that a serviceability check was actually carried out. The research recommended that AS1720.1 method be changed to a serviceability check, for example similar to the deflection check, so that designers can limit the deformation required and also account for creep.

It was also found that the *effective length* in calculating the buckling capacity of a stud is effected considerably by the stiffness of the wall plate used. As the stiffness of the wall plate increased, the *effective length* shortened substantially increasing the capacity of the stud. It is recommended that further work in this area be carried out as the current method contained within the timber engineering standard will heavily penalise wall systems that utilise stiff wall plates or stud to stud connections.

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INTRODUCTION

The amendment to the 2016 Building Code of Australia allowed timber buildings up to 25 m for residential and office construction. The regulation change only supplied fire resistant solutions and did not provide information on how to design or build a cost effective and functional timber framed building.

One of the key differences in the design of taller timber framed buildings to that of traditional timber framed houses is the consideration of axial shortening of the timber framing i.e. the building's overall height will reduce over time and be different depending on the number of storeys below i.e. top storeys will be worst affected compared to the lowest storey. Axial shortening causes issues with building elements as they can become hung-up on vertical elements such as exterior cladding, cores and service shafts. These elements include flashing, windows and door frames as well as plumbing and other services that may be broken at the junction of horizontal and vertical stacks. Other examples are the floor alignment to the lift and stair cores, as well as cracking building' coverings.

All buildings irrespective of material will experience axial shortening, for example concrete may settle 1.5 to 3 mm per meter of height. Due to the longer time a concrete building takes to be constructed much of its settlement occurs during the construction phase. Timber buildings on the other hand are much quicker to build and likely to settle during the fixing of the linings, services and the initial occupation stage.

There are many reasons why timber framed buildings shorten after construction, these include timber shrinkage, perpendicular to grain compression of horizontal elements, deflection of horizontal elements, creep of timber in compression and deflection, connection slippage and timber tolerances. Much of this can be reduced by changes in building practices where horizontal elements are taken out of the load path. Techniques like balloon and semi-balloon framing will reduce these issues but there will always be some horizontal element within the load path such as the top and bottom plates in the timber wall framing; the two principal effects still remain being timber shrinkage and compression perpendicular to grain.

This project investigates one of these subjects being perpendicular to grain compression. The aim of the project is to validate the assumption used within the Australian Standard AS1720.1 for calculating compression perpendicular to grain for common timber species and to develop practical methods to reduce compression deformation.

The project was conducted in four stages:

1. Desk top investigation of the aforementioned issues to find other research on the subject as well as to discover potential solutions.

2. Test bearing capacity of common timber species and methods to reduce compression deformation found from desk top research.

3. Full scale wall frame testing on five candidate solutions as well as a control sample (6 overall) to verify the effectiveness of methods to reduce compression deformation.

4. Development of an easy to read guide on the project's outcomes.

METHODOLOGY

The project was conducted in four stages:

1. Desk top investigation

2. Test bearing capacity of common timber species and methods to reduce compression deformation found from the desk top research phase

3. Conduct full scale wall frame testing on five candidate solutions as well as a control sample (6 overall) to verify the effectiveness of methods to reduce compression deformation

4. Develop an easy to read guide on the outcomes from the project

Desk-top Investigation

This stage investigated the available literature on the subject of axial shortening with particular reference to compression perpendicular to grain. The study purpose is to also suggest methods to reinforce or provide less compression deformation.

Bearing capacity of common timber species and methods to reduce compression

A series of bearing strength perpendicular to grain tests (around 740 individual tests) were carried out in accordance to the Australian Standard AS/NZS 4063.1[1]. The tests were conducted on a range of common timber species, engineered timbers, wall plate configuration, stress grades and reinforcement methods as listed below.

Timber species:

- Alpine Ash
- Australian Radiata pine
- American Douglas fir
- Blackbutt
- Cypress
- European spruce
- Flooded gum
- Ironbark
- Karri
- New Zealand Radiata pine
- Silvertop Stringybark
- Spotted gum

Engineered Timbers:

- Laminated Veneer Lumber
- Cross Laminated Timber
- Laminated Strand Lumber

Wall Plate and Stress Grade Configuration:

- Stress grade variation, MGP10 and MGP12
- Two wall plates
- Three wall plates
- 3 mm notched wall plates

[1] AS/NZS 4063.1:2010 Characterization of Structural Timber Part 1: Test Methods

Reinforcement methods:

- 2 x 40 mm fully threaded screws, without steel plate
- 3 x 40 mm fully threaded screws, without steel plate
- 4 x 40 mm fully threaded screws, without steel plate
- 2 x 2.5 x 40 mm flathead nails
- 3 x 2.5 x 40 mm flathead nails
- 4 x 2.5 x 40 mm flathead nails
- 2 x 40 mm fully threaded screws, with 6 mm steel plate
- 3 x 40 mm fully threaded screws, with 6 mm steel plate
- 2 x 2.5 x 40 mm flathead nails with 6 mm steel plate
- 3 x 2.5 x 40 mm flathead nails with 6 mm steel plate
- 4 x 2.5 x 40 mm flathead nails with 6 mm steel plate
- 1 screw 6 x 140mm, full thread, cylindrical head
- 2 screw 6 x 140mm, full thread, cylindrical head
- Claw Nail plate 120 x 40mm on one side of stud and plate
- Claw Nail plate 120 x 40mm on both sides of stud and plate
- Metal angle bracket to one side of stud
- Metal angle bracket on both sides of stud
- Stud tie strap
- Plywood sheathing on one side of frame
- Plywood sheathing on two sides of frame
- 2 screws 6 x 120 mm, partial thread and conic head
- Claw Nail plate 50 x 25 mm on both sides
- Nail plate 125 x 45 mm on one side, nails 3.7 x 38.1 mm
- Nail plate 125 x 45 mm on both sides, nails 3.7 x 38.1 mm
- Nail plate 125 x 75 mm on one side, irregular holes, nails 3.7 x 38.1
- Nail plate 125 x 75 mm on both side, irregular holes, nails 3.7 x 38.1
- 1 screw 5.6 x 152 mm, partial thread, washer head
- 2 screw 5.6 x 152 mm, partial thread, washer head
- Bearing plate 130 x 80 x 6 mm
- CLT - 2 vertical layers upwards
- CLT - 1 vertical layer upwards

Test Procedure

Every species or reinforcement method has been tested 5 times in accordance to the procedure in AS/NZS 4063, refer Figure 1. This involved placing a 50 mm bearing plate at the centre of each timber specimen; testing 5 times in the middle of the specimen. In addition to this the same test was conducted 5 times at the end of the specimen. Each specimen was loaded so that 2.5 mm deformation occurred within 5 mins.

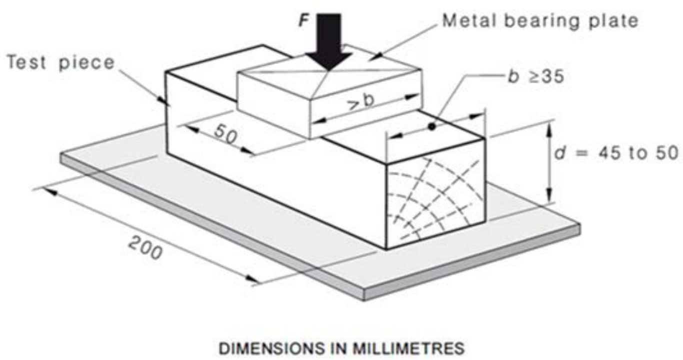


Figure 1: AS/NZS 4063 Perpendicular to Grain Test Step Up

Ten bearing tests were carried out for each species or method of reinforcement. To reduce variations from within the timber species all 10 samples were cut from a same length of timber.

Where reinforcement methods were used the specimens included a short timber stud to model the wall stud and plate interface, refer to Figure 2. Furthermore, each test sample was checked against a sample without reinforcement. The sample without reinforcement was cut from the same length of timber to remove any variables.

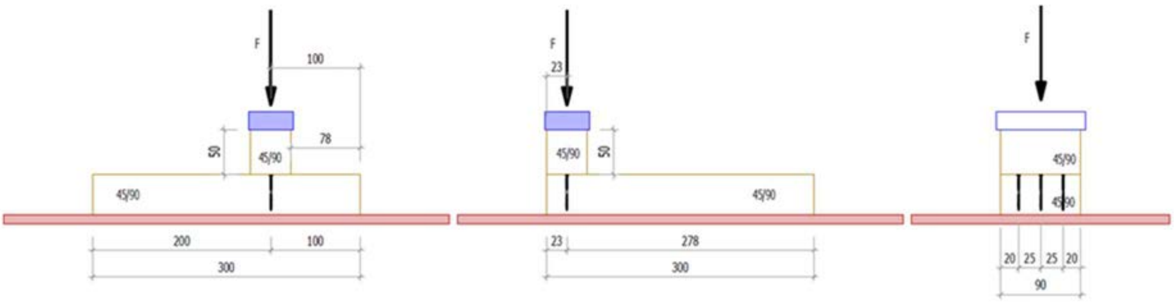


Figure 2: Illustration showing a short stud added to the bearing test configuration to allow for the placement of a reinforcement

Full Scale Wall Frame Testing

For the bearing tests conducted in Stage 2 five candidate solutions plus a control sample (6 overall) were chosen to verify the effects of each method to reduce compression displacement. The full scale tests were conducted to gauge if there were any other effects from size that had not been encountered within the initial bearing tests performed to AS/NZS 4063, i.e. a limited proof of concept test.

The test involved the loading of a full scale (2.7 m high) timber framed wall with a candidate either reinforced or with a superior wall plate that was selected in phase two of this research project. The wall frame used was 2.7 m high and 1.8 m long with 90 x 45 LVL studs evenly spaced at 450 mm centres. The full-scale wall configuration is represented in Figure 3.

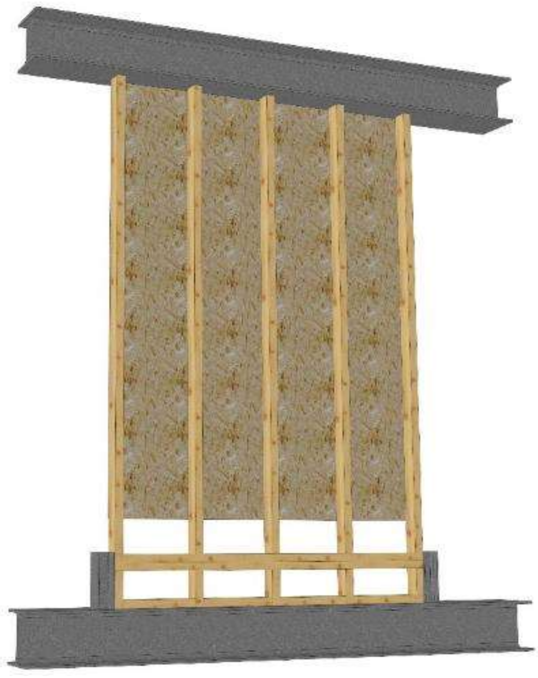


Figure 3: Illustration of the Full Scale Wall Test

To remove the influence of the floor joist within the wall configuration a semi balloon framing detail was used. To complete the semi balloon framing configuration a short wall below the 2.7 m high wall framing was included.

The wall frame was placed between a strong floor and very stiff steel beam on which the load is applied, refer Figure 4. The wall studs were in direct contact with the steel beams or floor without any mechanical connection and the stud ends were held in place by a timber frame (not shown in Figure 3). The stud ends were clean cut and straight to remove any influence the studs may have on the test results.

Figure 4: Hydraulic Press at Western Sydney University, Kingswood Campus

The stud material used in the wall frame was generally made from maritime pine LVL to be as close as possible to the limits of the bearing capacity of the wall plate being examined; Only 2 samples of each wall configuration was tested due to time and budget constraints. A 6.0 mm OSB panel was nail fixed to the wall frame to resist the minor buckling of the studs.

Wall Configuration Tested

Control – MGP 10 Wall Plates
To be able to form a comparison between the different methods of wall plate reinforcement, a wall frame without reinforcement was tested. The reference wall was built with a Radiata pine MGP 10 wall plate connected to the studs with two nails in accordance to AS 1684.2[2], refer to Figure 5.

Cypress Wall Plate
The same detail considered in the Control test has been used but the wall plate has been replaced with Cypress. The previous testing program showed that Cypress performed well, likely due to the higher density Cypress has over MGP10 pine.

[2] AS 1684.2 Residential timber-framed construction Non-cyclonic areas

Victorian Ash Wall Plate
The same detail considered in the Control test has been used but the plate was replaced with Victorian Ash. Victorian Ash is a medium density hardwood in comparison to other hardwoods found in Australia.

Cross Laminated Timber Wall Plate
The same detail considered in the Control Test has been used but the plate was replaced with Cross Laminated Timber, refer Figure 6. The CLT is constructed from three laminations and is 45 mm thick with the outer laminations having the grain in line with the stud direction.

Screw Reinforced Wall Plate to Stud
Instead of connecting the plate and the stud with nails, the connection is made with 2 x 8 mm diameter x 160 mm long full thread with washer head SPAX screws, refer Figure 7.

Stud on Stud Bearing
This configuration used direct stud on stud bearings with noggings placed between each stud, refer to Figure 8.

European Method – Stud on Stud
This configuration is an additional test in the research program which represents a wall/floor arrangement used widely in Europe to minimise axial shortening of tall timber framed buildings. It comprises of the stud notched at its upper ends to provide space for the floor. The wall frame above sits on the floor and the lower notched stud ends. Noggings are placed between the wall studs as in the Stud on Stud Bearing above. This allows part of the stud to be in direct contact with each other, refer Figure 9.

The studs used for this configuration are MGP10 140 x 45 mm with a 45 mm deep notch. Therefore the results cannot be compared with the above test results and are used as an indicator of the efficiency of this system.

Figure 5: Control Wall Frame - MGP10 plates

Figure 6: CLT Wall Plates

Figure 7: Screw reinforced Wall Plates

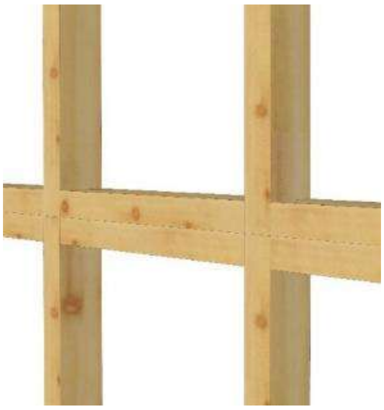


Figure 8: Direct Stud on Stud Bearing


Figure 9: European Notched Stud Direct Bearing Method

Guide on the project's outcomes

Text for a guide was also planned to be produced on the outcomes and findings from this testing. This activity was not possible as the project's conclusion found that perpendicular to bearing within AS1720.1 was too misleading to successfully develop a guide of any value.

RESULTS

Literature Review

The first stage of the project was to investigate the knowledge in this area and to identify common methods to reduce perpendicular to grain compression. Refer to the report titled *Desktop Investigation - Study the influence of perpendicular to grain compression and creep in 4 to 8 Storey Lightweight Timber Framed Buildings*.

It was found that Sweden and the United Kingdom had conducted research on compression perpendicular to grain for tall timber framed buildings. The most notable work was conducted in the United Kingdom under the British Research Centre's project TF 2000[3]. This project constructed a full scale 6 storey timber framed apartment building within a hangar in Wales and investigated a number of building physics issues including shrinkage, axial movement, fire resistance and acoustics.

The testing showed the main reasons for axial shortening was timber shrinkage and compression movement as the sawn timber used in the project was partially seasoned, around 19% moisture content. Their recommendation was to use timber dried to 12% moisture content, a commonly available timber moisture content within Australia.

Other notable work was from FPInnovation[4] in Canada who investigated movement and shrinkage in a number of actual buildings. They found shrinkage accounted for 57% of the overall axial shortening in the buildings and the remaining movement was attributed to compression, deflection and settlement. This is comparable to the project in the United Kingdom where partially seasoned sawn timber was also used in the research dominating the reason for the building's movement.

[3] Grantham R., Enjily V., et al, Multi-storey timber frame buildings, BR454, BRE, UK, 2003
[4] FPInnovation, Update of Vertical Movement Monitoring in Six-Storey Wood- Frame Building in British Columbia, 2017

Most of the remainder of the decktop research investigated methods to reinforce against perpendicular to grain crushing. Already mentioned above axial displacement reduction in Europe and North America timber framing was about reducing shrinkage effects not crushing, therefore no method was discovered in this regard. Where discussion was found it was on methods to reduce perpendicular to grain crushing for glulam beam and CLT walls on CLT floors. For these systems screws and metal plates were the most common reinforcement method used.

Bearing Capacity of Common Timber Species and Methods to Reduce Compression

The outcome of this phase of the research was aimed to influence the choice of five candidate solutions to be tested in a full-scale format. The conclusions from the research are reported in the document *Perpendicular to grain bearing tests on common timber species, engineered timber and reinforcement methods.* The main findings are summarised below.

Timber species

Table 1 summarises the results from bearing Perpendicular to grain tests on common timber species in accordance to AS/NZS 4063. The results are for the 'middle' condition, more than 75 mm from the end of the length of timber. AS 1720.1[5] comparison values include the base value and the value modified for the bearing length of 45 mm; all timber was sourced as sawn timber.

Table 1: Perpendicular to Grain Bearing Capacity – AS1720.1 Values versus Test Results

	AS 1720.1 Values			Test Values	
Timber Species	**Density ADD kg/m^3 (Table H2.3 and H2.4)**	**Bearing perpendicular to grain (MPa) 150 mm length**	**Bearing perpendicular to grain (MPa) adjusted for k7 bearing length of 45 mm (MPa)**	**Density ADD kg/m^3**	**Bearing perpendicular to grain (MPa)**
Spotted Gum	1100	23	28.5	1169	54.2
Red Ironbark	1050	19	23.6	1078	39.7
Blackbutt	900	23	28.5	1000	32.6
Karri	900	23	28.5	880	31.7
Silvertop Stringybark	850	23	28.5	890	22.9
Flooded gum	850	19	23.6	840	21.6
Alpine Ash	650	17	21.1	600	15.0
Cypress	700	10	12.4	690	26.5
American Douglas Fir	550	13	16.1	470	9.3
MGP10 NZ Radiata pine	550	10	12.4	500	10.5
MGP10 Radiata pine (S1)	550	10	12.4	450	8.6
MGP10 Radiata pine (S2)	550	10	12.4	460	10.1
MGP12 Radiata pine (S1)	550	10	12.4	523	10.2
MGP10 European Spruce	460*	10	12.4	396	6.4

Note: 1. S1 and S2 refer to Supplier 1 and Supplier 2
2. Density from Wood in Australia, Bootle, 2005

The Stress/Deformation curves are from the averages of 5 repeats shown for softwood timber species in Figure 11 and for hardwood timber species in Figure 12.

[5] AS 1720.1-2010 Timber structures Design methods, Standards Australia

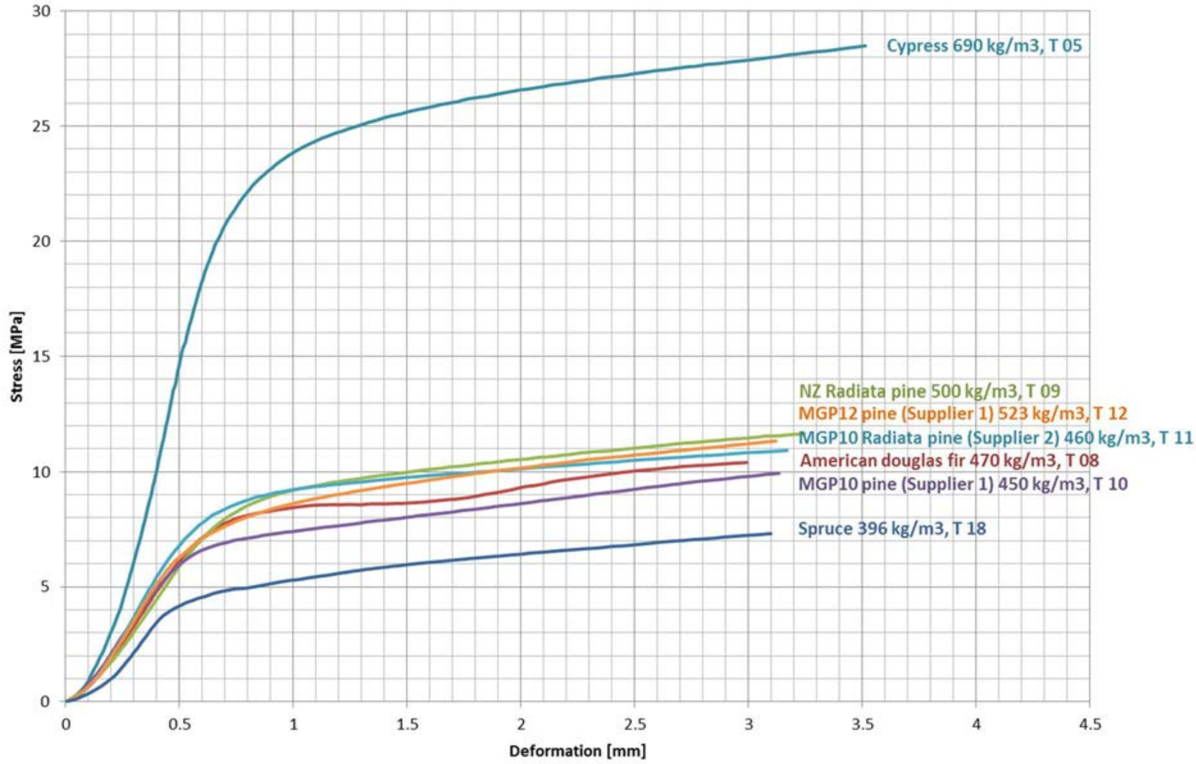


Figure 11: Various Softwood Stress (MPa) versus Deformation (mm)

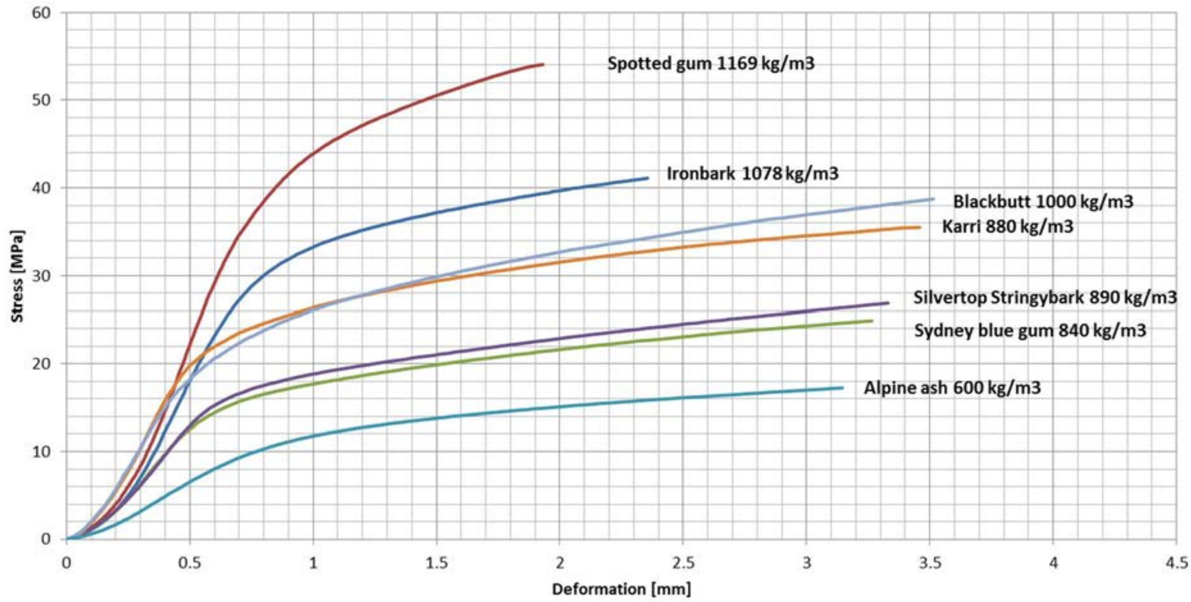


Figure 12: Various Hardwood Stress (MPa) versus Deformation (mm)

Engineered Timber

Three different manufacturers of LVL were randomly sourced and tested and the results for Perpendicular to grain bearing tests are in Table 2 below. The base timber species used in the LVL varied from Spruce, Maritime pine and Douglas fir. The Stress/Deformation curves are shown in Figure 13 and the results were generally in line with manufacturer's published information but as it's not known how the manufacturer obtained the values, no correction of bearing length has been applied. For the CLT samples no manufacturer's values were available as the application used in this testing is not commonly used.

Table 2: Engineered Timber Manufacturer's Values against Tests Outcomes

		Manufacturers Values		Test Values	
	Species	**Density ADD kg/m3**	**Bearing perpendicular to grain (MPa)[1]**	**Density ADD kg/m3**	**Bearing perpendicular to grain (MPa)**
LVL Supplier 3	Maritime	650	12.0	690	13.0
LVL Supplier 4	Mixed spruce and pine	NA	6.0	517	5.7
LVL Supplier 5	Douglas fir	NA	5.6	610	8.7
LVL on edge Supplier 5	Douglas fir	NA	10.7	610	17.8
LSL	Various softwoods	745	8.0	800	8.4
CLT 2 vertical layers in load direction	Spruce	450	NA	475	30.9
CLT 1 vertical layer in load direction	Spruce	450	NA	466	16.3

Note:
1. Some values quoted from the manufacturer are likely not to have been conducted in direct accordance with AS/NZS 4063 as the source of the published values are not referenced and therefore have not been corrected for length factor.

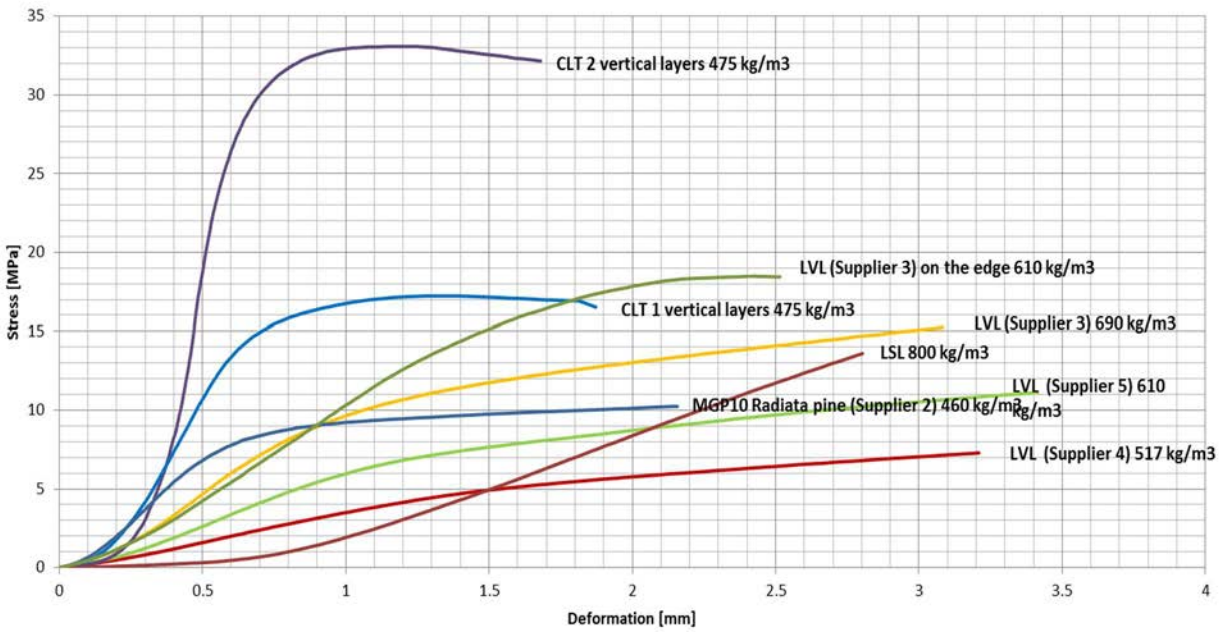


Figure 13: Stress/Deformation Curves for Various Engineered Timber

Wall Plate Configuration

Multiple Wall Plates versus Single Plates

The total deformation of the wall plates was higher for the same load when more wall plates were added, refer to Figure 14.

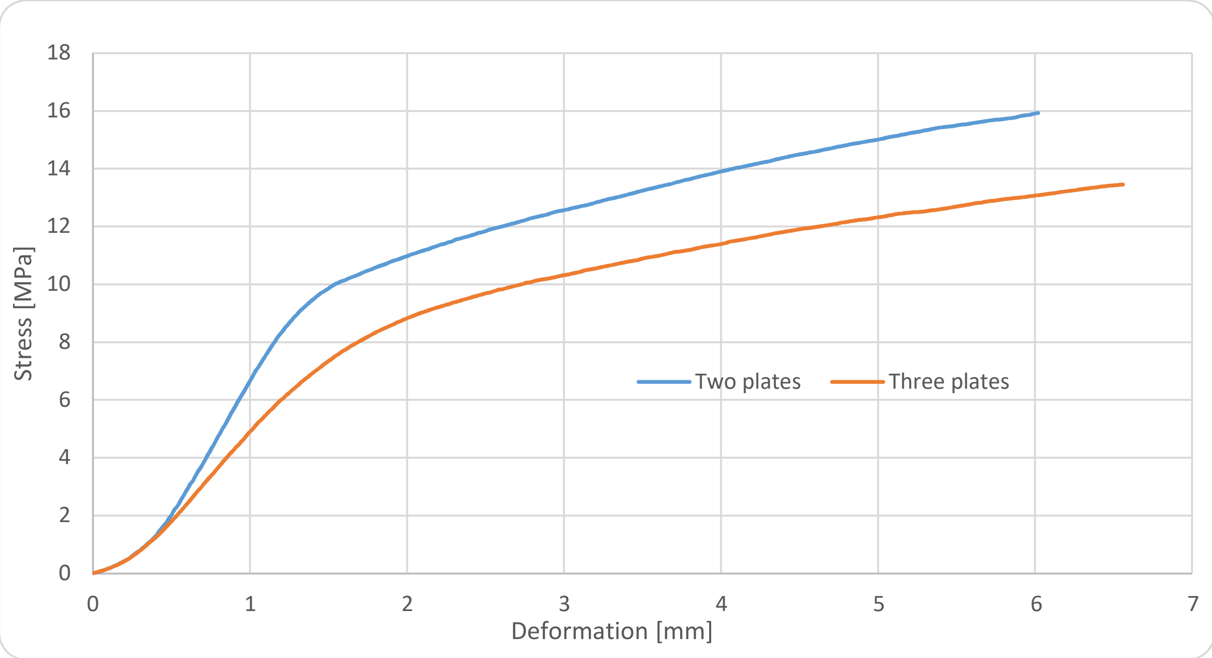


Figure 14: Stress/Deformation Curves for Multiple Wall Plates

3 mm trench plate

The outcome was observed to be highly variable during the initial phase of loading. This variation was attributed to the rough surface formed in the trench as it was not possible to obtain a perfectly flat trench. The results show no real difference to the trenched plate and non-trenched plate at 2.0 mm deformation, refer Figure 15.

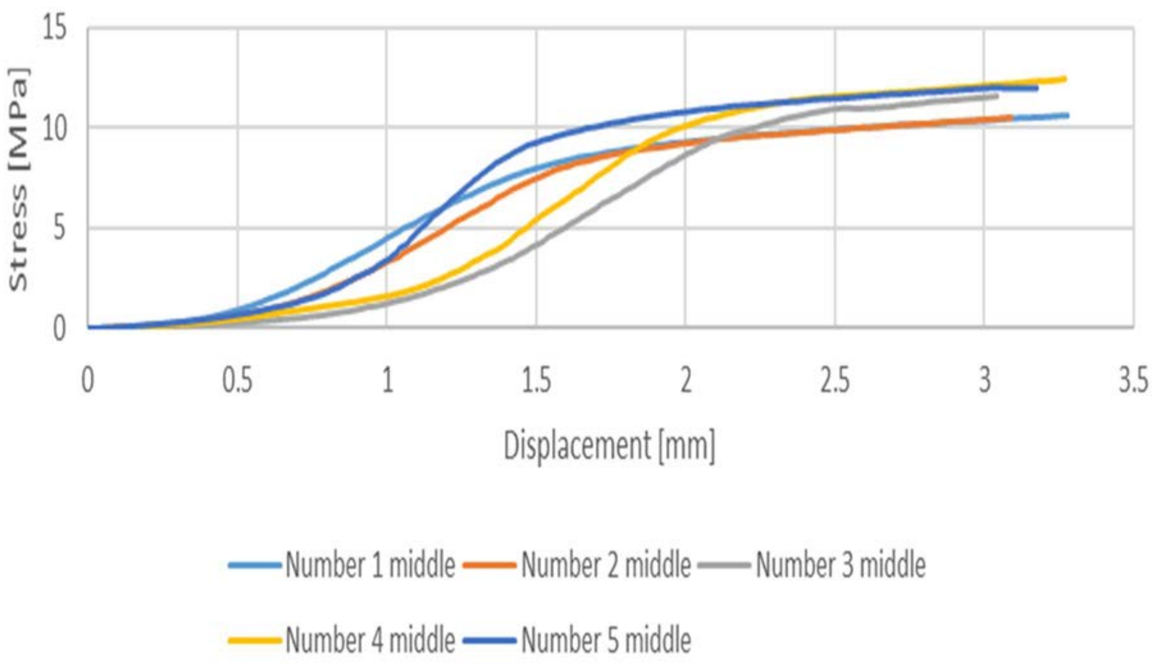


Figure 15: Stress/Deformation Curves for 3 mm Trenched Plates

MGP10 versus MGP12

For the one supplier of Radiata pine two different stress grades were compared, MGP10 to MGP12. The results showed an approximate 20% difference between the values at 2.0 mm deformation, refer Figure 16. The difference can be attributed to the variance in densities

MGP10 – 450 kg/m^3 to MGP12 – 523 kg/m^3 so they observed a relationship of Perpendicular to Grain bearing resistance to density. Refer to the discussion section of this report.

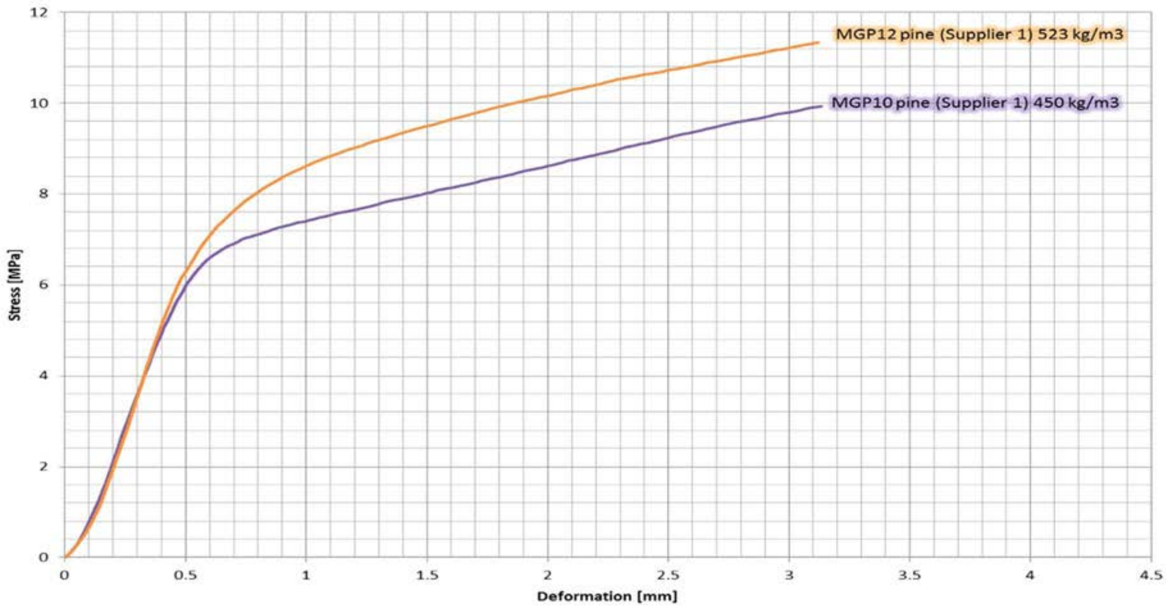


Figure 16: Stress/Deformation Curves for 3 mm Trenched Plates

Reinforcement Method

Numerous configurations of reinforcement using either fully threaded or partially threaded screws with one or two screws per sample were investigated. The outcome of the testing is shown in Figure 17, where the screw reinforcing was below, similar to or slightly improved over the non-reinforced reference sample.

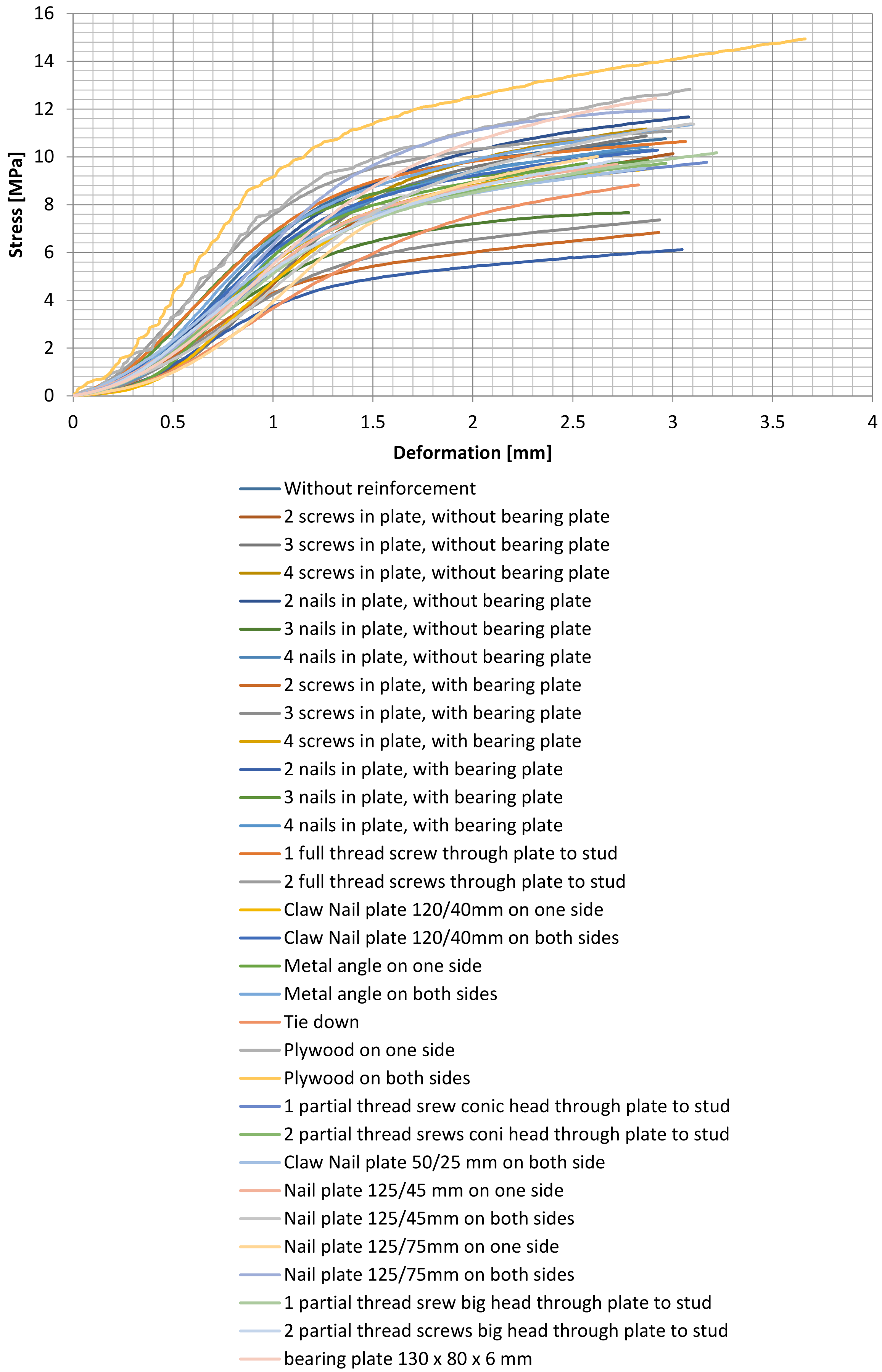


Figure 17: Stress/Deformation Curves for Screw Reinforced Plates

Variables Investigated

A number of other variables were investigated beyond the project's scope to assist in the understanding of the bearing capacity of wall plates. These included loading methods such as short studs versus metal plates as the screw reinforcement testing could not account for the metal bearing plate prescribed in AS/NZS AS 4063. The results are summarised in the following.

End versus Middle of Plate Loading

The research compared the loading at the middle of the sample and at the end of the specimen in accordance with AS/NZS 4063. The results showed a 20 per cent reduction in capacity at the end of the specimen, refer to Figure 18.

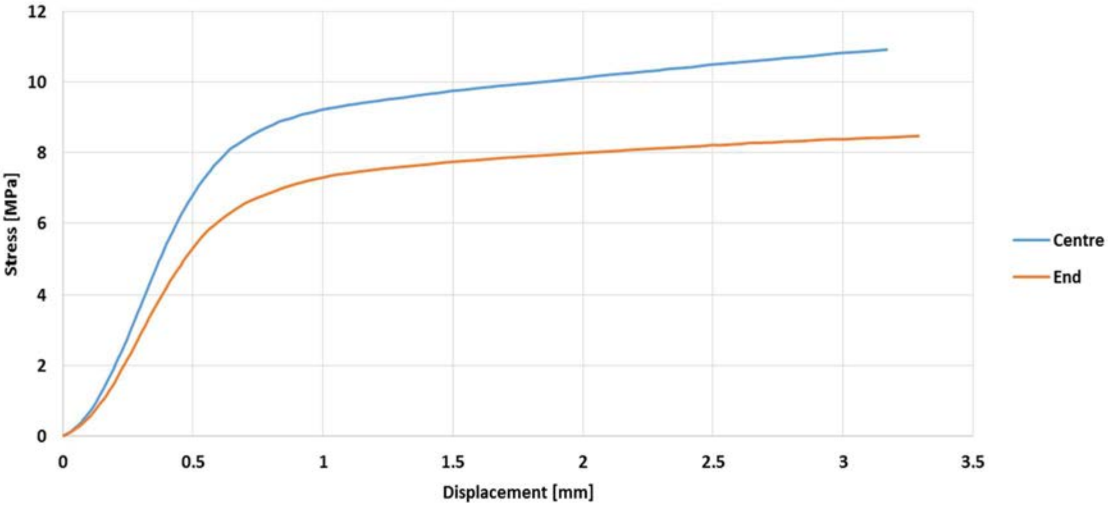


Figure 18: Stress/Deformation Curves for End versus Middle of Plate Loading

Bearing Surface: AS 4063 Steel Plate versus Timber Stud

The study also compared the difference in capacity depending on the loading method bearing surface, i.e. metal plate in accordance to AS/NZS 4063 and a stud end, refer Figure 19.

Results from the testing using the metal plate prescribed in AS/NZS 4063 were 10 to 15 per cent higher than those using a timber stud of the same contract area. The timber stud loading method represents a more realistic situation in wall framing, stud bearing onto a wall plate. It was observed during the test that the stud end also received some deformation, therefore this embedment was included in the total deformation of the system, producing a lower capacity for the system.

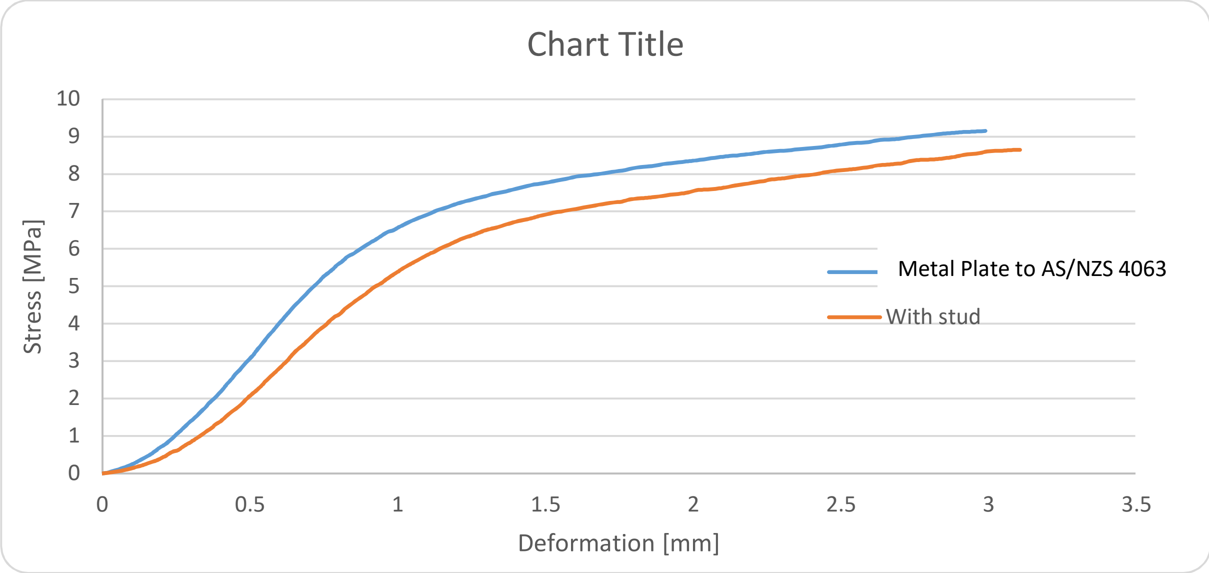


Figure 19: **Stress/Deformation Curves Comparison between AS 4063 Steel Plate and Timber Stud Loading**

Bearing Surface - AS/NZS 4063 Steel Plate versus Timber Stud with Nail Fixing

A comparison was also carried out where the stud configuration includes driven nails as done in fabrication, refer to Figure 20. The difference observed between Figure 19 and Figure 20 indicated the difference between the metal plate loading method and the stud with nails was eliminated at the 2.0 mm displacement mark. For displacement less than 2.0 mm the stud with nails crushed earlier than the metal plate.

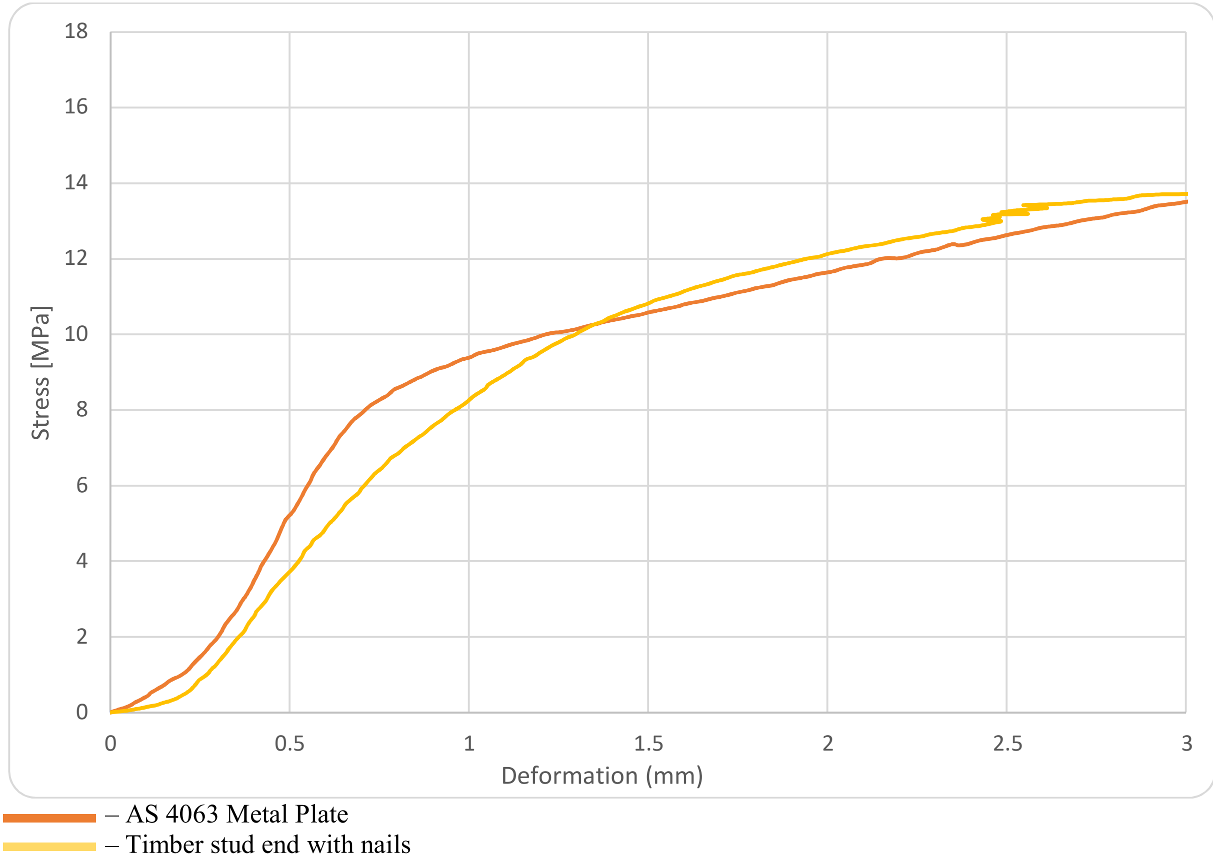
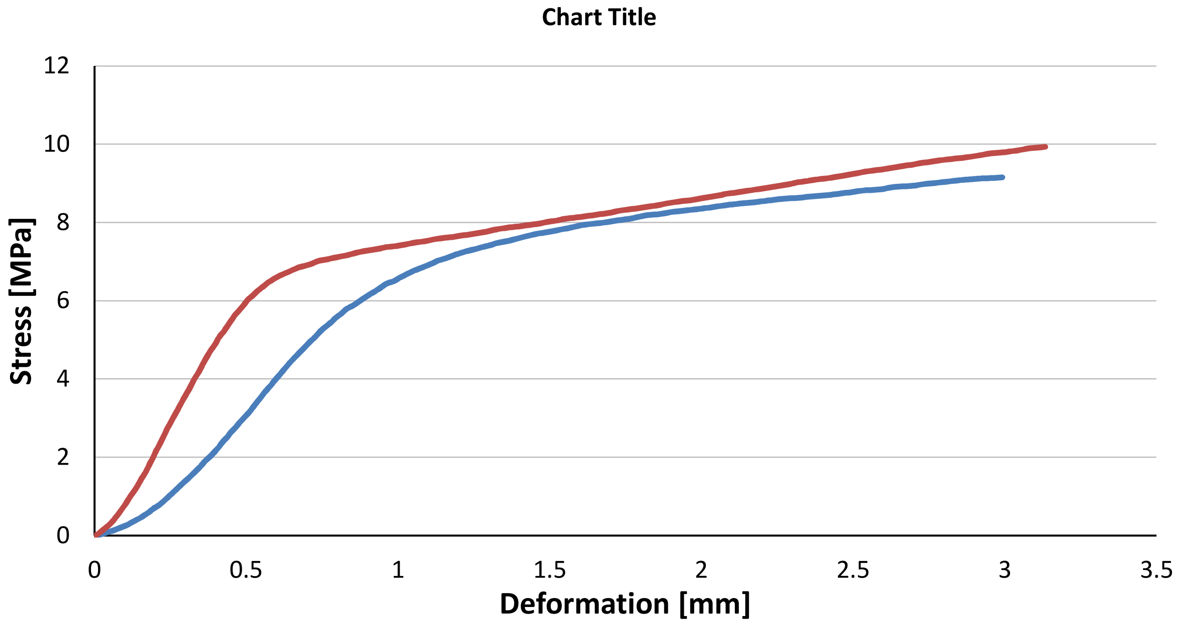


Figure 20: AS/NZS 4063 Steel Plate versus Timber Stud with Nail Fixing

Milled Finish: Smooth versus Rougher Headed

It was also found that smooth milled surface wall plates had less initial deformation compared to rougher headed (grooved) wall plates, refer to Figure 21. The initial deformation of the rougher headed wall plates can be attributed to the grooves in the timber surface collapsing upon applying the load. However once the grooves had been crushed the results overall were similar to smooth milled surface wall plates.



– Rougher Headed (grooved surface)
– Smooth surface

Figure 21: Milled Finish: Smooth versus Rougher Headed

For the purpose of the next research phase five candidate systems for full scale testing were short listed. The systems recommended were:

1. Cypress wall plates
2. Hardwood (Victorian Ash) wall plates
3. CLT Wall Plates (two vertical lamination in load direction)
4. Fully Threaded Screws
5. Avoiding wall plates in the load path (direct stud end to end bearing)

Full Scale Tests

The purpose of this phase of research was a proof of concept for the various reinforcement methods found in the previous research phase. The systems that were investigated include a Cypress wall plate, Victorian Ash wall plate, CLT wall plate, screw reinforced wall plate and stud on stud.

MGP10 Wall Plate (Reference Test)

The tests for this configuration were stopped before its ultimate load was achieved because of the very large deformation occurring within the wall plate, refer to Figures 22 and 23. Both tests were stopped around 240 kN but could have supported higher loads.

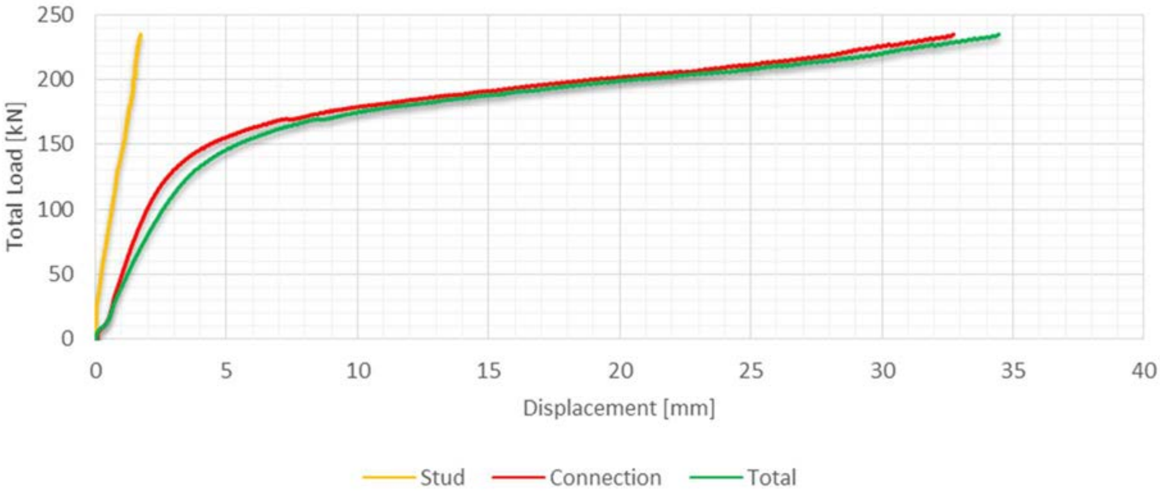


Figure 22: Test 1.1 D - MGP10 Wall Plate

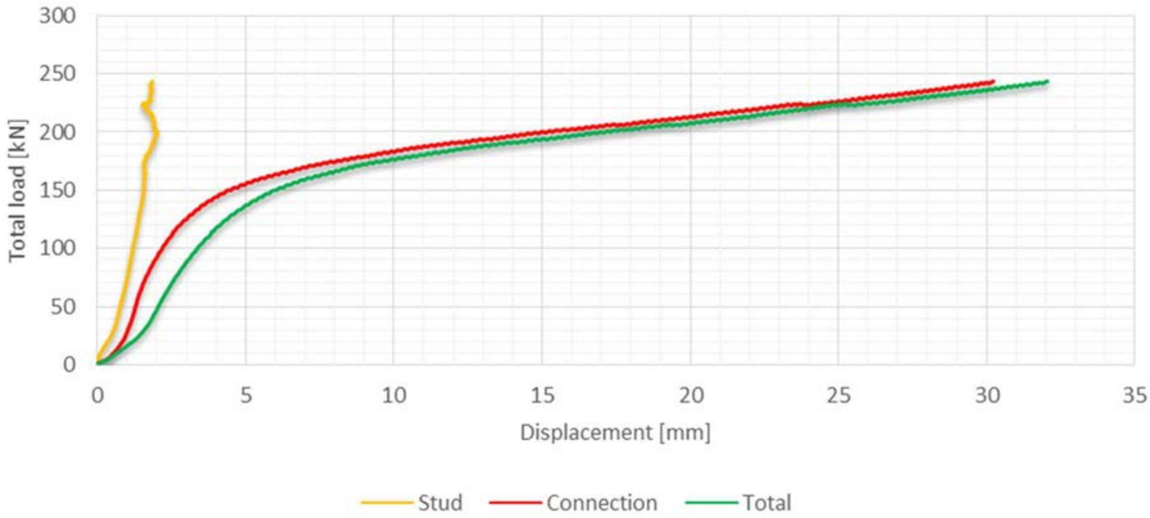


Figure 23: Test 1.2 B - MGP10 Wall Plate

It was observed that the studs did not suffer any major or minor buckling as the plate just continued to crush. The measured horizontal movement of some millimetres in the major axis direction was due to the bottom of the stud moving in that direction, refer to Figure 24.

Figure 24: Large deformation of MGP10 Wall Plates

Cypress Wall Plate

The ultimate capacity of Test 2.1 D was 430 kN and Test 2.2 B was 400 kN, refer to Figures 25 and 26.

The mode of failure was buckling in the major axis as the Cypress plate allowed rotation as it crushed to one side of the wall plate, refer Figure 27. Deformation was initially greater in Test 2.2D due to the wall plates being bowed and the initial movement in this test was this bow seating itself against the strong floor.

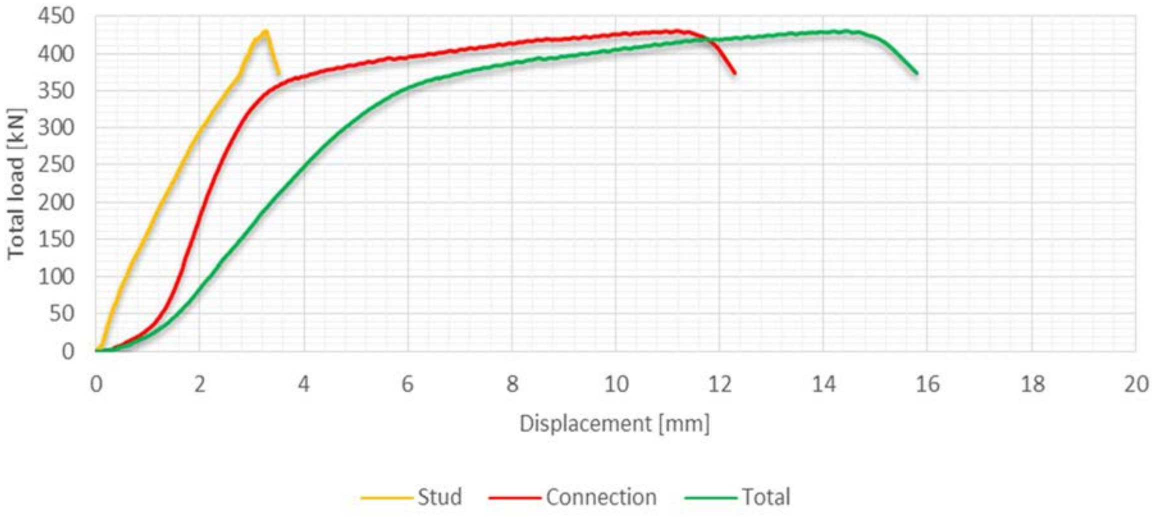


Figure 25: Test 2.1 D - Cypress Wall plate

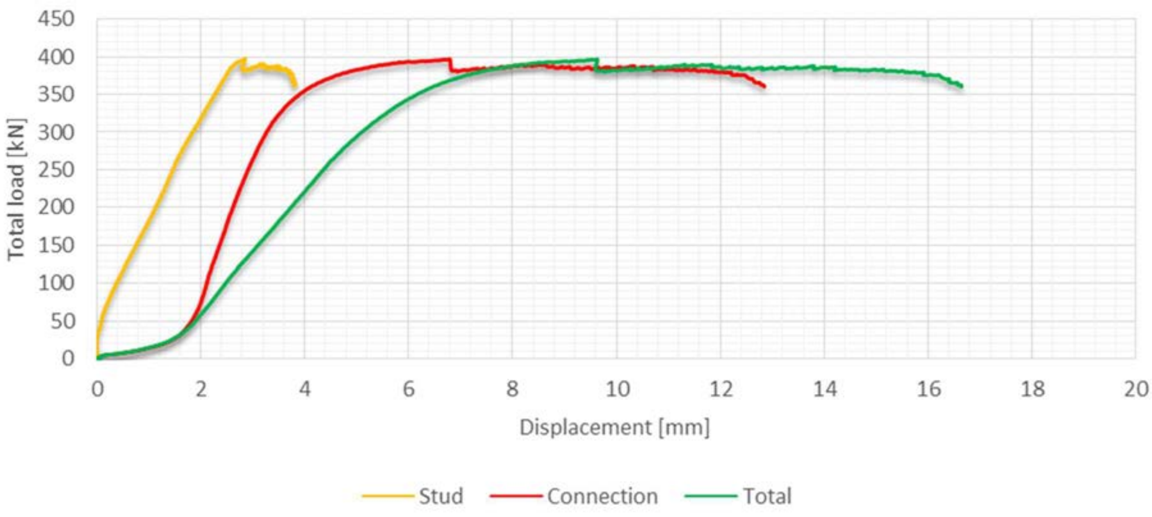


Figure 26: Test 2.2 D - Cypress Wall Plate

Figure 27: Indentation in the Cypress wall plate caused by rotation of the stud

Victorian Ash Wall Plate

The two walls investigated did not produce the same results as Test 3.2 B was the very first specimen tested in the series and it contained some imperfections in the fixing of the OSB panel that allowed buckling of the wall in the minor direction, refer to Figure 28. Test 3.1 D and all other specimens had this issue addressed with better fixing of the OSB panel. Therefore Test 3.2 B ultimate capacity should be disregarded in favour of Test 3.1 D, refer to Figure 29.

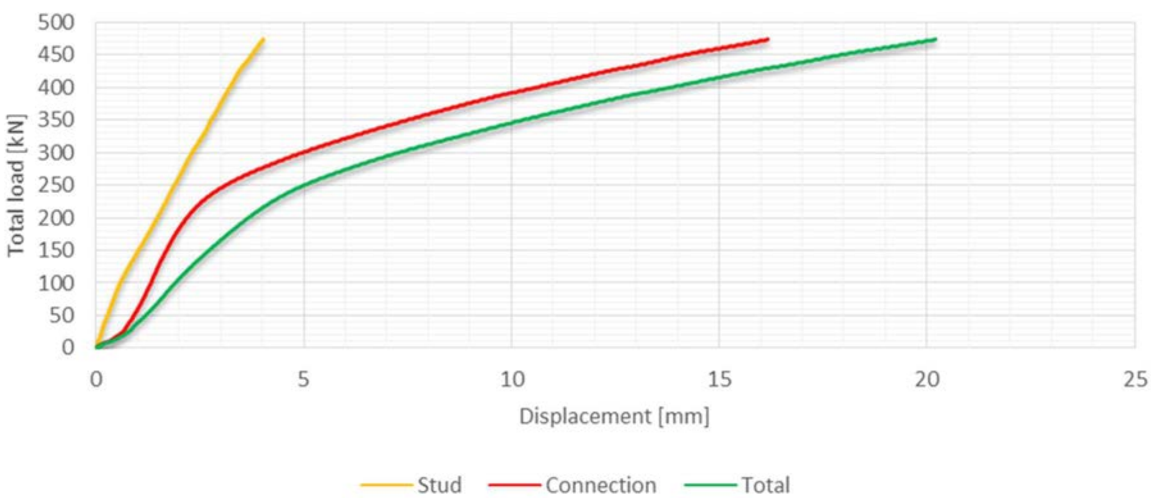


Figure 28: Test 3.1 D - Victorian Ash Plate

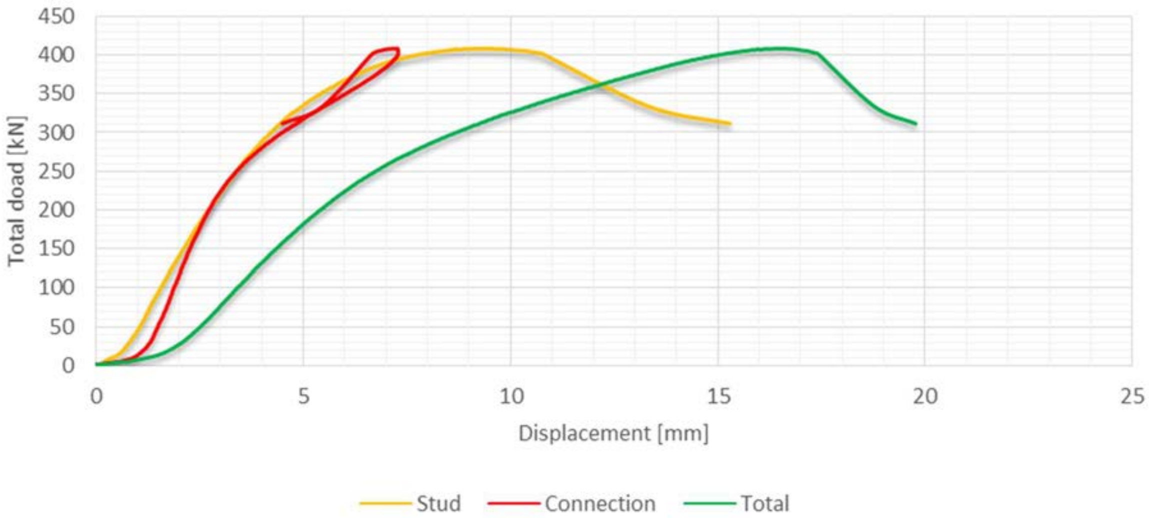


Figure 29: Test 3.2 B - Victorian Ash Plate

Test 3.1 D and Test 3.2 B preformed similarly in bearing capacity of the wall plate during the elastic phase. Test Wall 3.1 D was stopped just before major axis buckling failure occurred at 473 kN, refer Figure 30. The displacement was quite low in the comparison to the reference specimen because of the good quality of timber used.

Figure 30: Test 3.1D - Victorian Ash Wall Plate

Cross Laminated Timber Wall Plate

Both tests performed similarly during the elastic phase with a much higher bearing capacity achieved when compared to the MGP10 reference test, refer to Figures 31 and 32. The ultimate capacity of Test 4.1 D was not achieved as the specimen rotated near its ultimate load due to the load cell twisting the spreader beam.

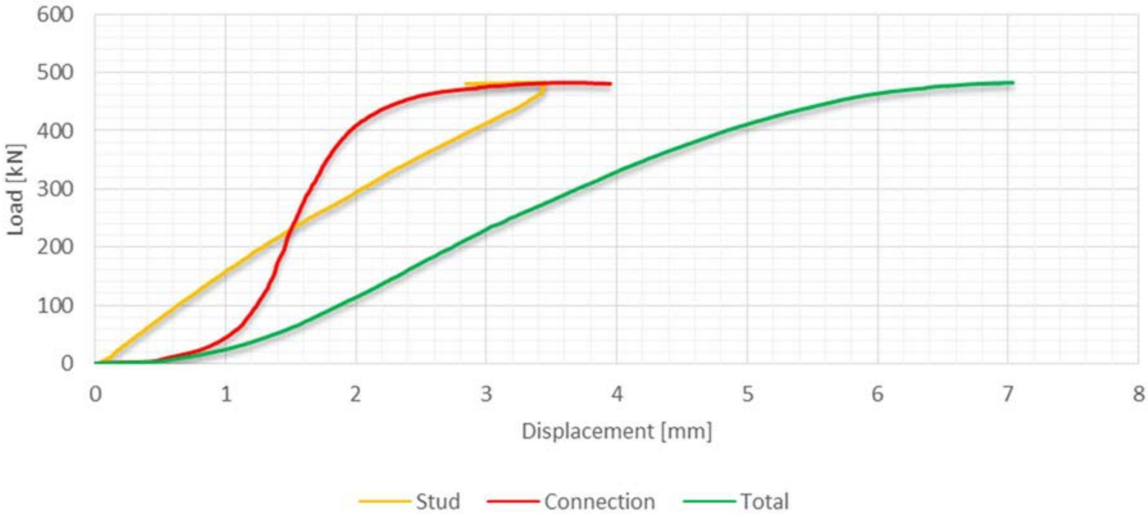


Figure 31: Test 4.1 D - CLT Wall Plates

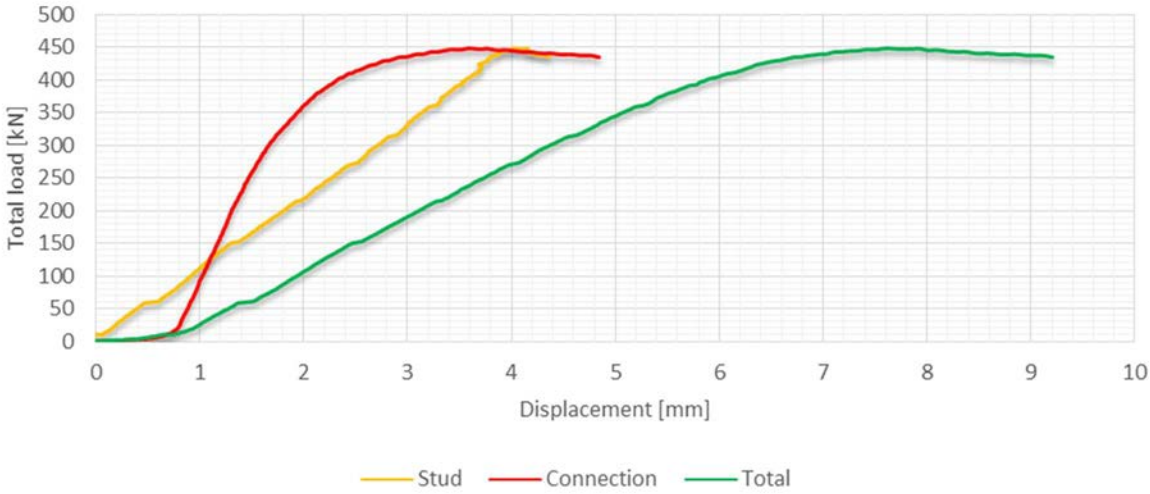


Figure 32: Test 4.2 B - CLT Wall Plates

Test 4.2 B was observed to split off the side of the CLT plate at around 449 kN causing a drop in load. The splitting of the CLT plate was detected to occur at the interface between the vertical and horizontal laminations. The splitting of the CLT wall plate and the impression of the end of the LVL stud are visible in Figure 33.

Figure 33: Indenting and Spiriting of CLT Wall

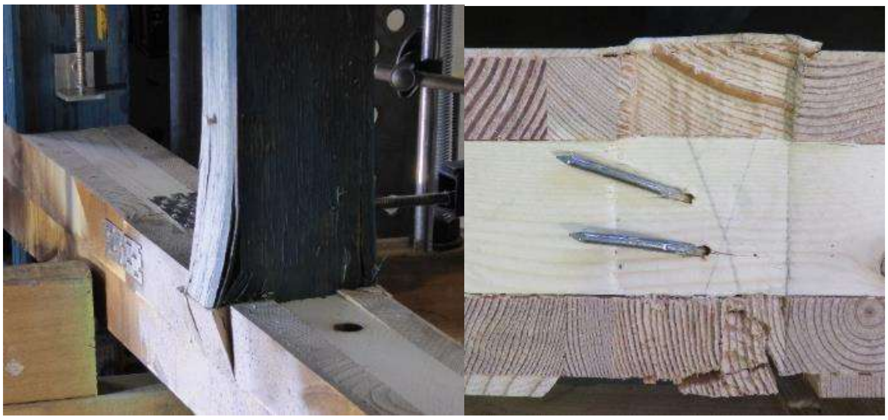


Figure 33 Continued: Indenting and Spiriting of CLT Wall

Fully Threaded Screws

The improvement of wall plates reinforced with fully threaded screws was marginally better than unreinforced MGP10 wall plates, refer Figure 34 and 35.

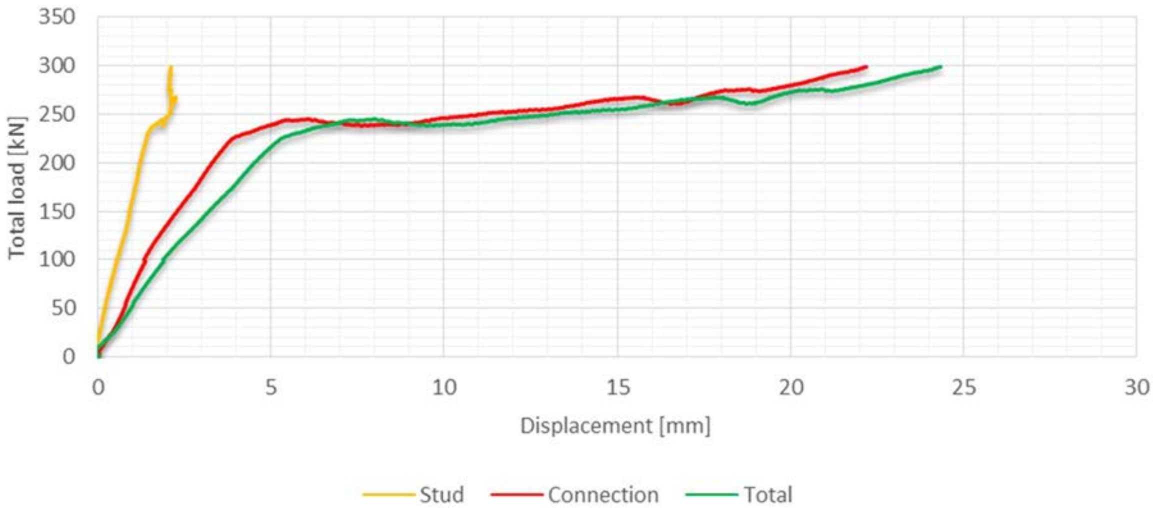


Figure 34: Test 5.1 D - Fully Threaded Screws

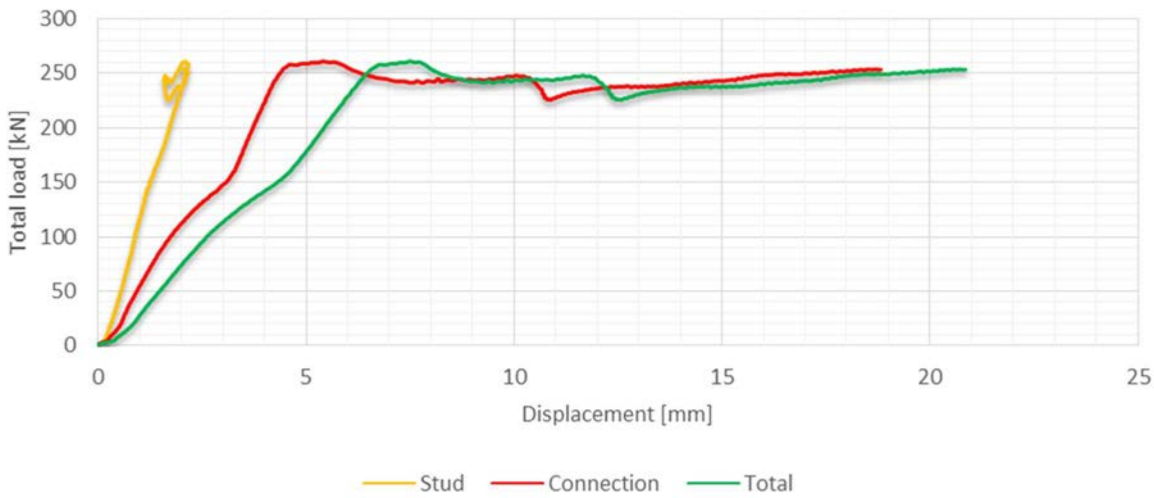


Figure 35: Test 5.2 B - Fully Threaded Screws

The ultimate failure mode for both walls was the splitting of the LVL studs. It was observed that after the screw reinforcement failed to take any further load, the wall plates themselves started to take most of the deformation, refer Figure 36. The plate at this stage could take some of this additional load but very large deformations had already occurred. The splitting stud did not always occur at the bottom stud as expected due to its short length but also occurred in the long stud as well.

Figure 36: Splitting of the LVL stud by the screw reinforcement

Stud on Stud

Both test results showed considerably less deformation than the reference test, refer Figures 37 and 38. A major axis buckling failure was observed at mid height in both tests resulting in an ultimate load of respectively 659 kN and 636 kN, refer Figure 39.

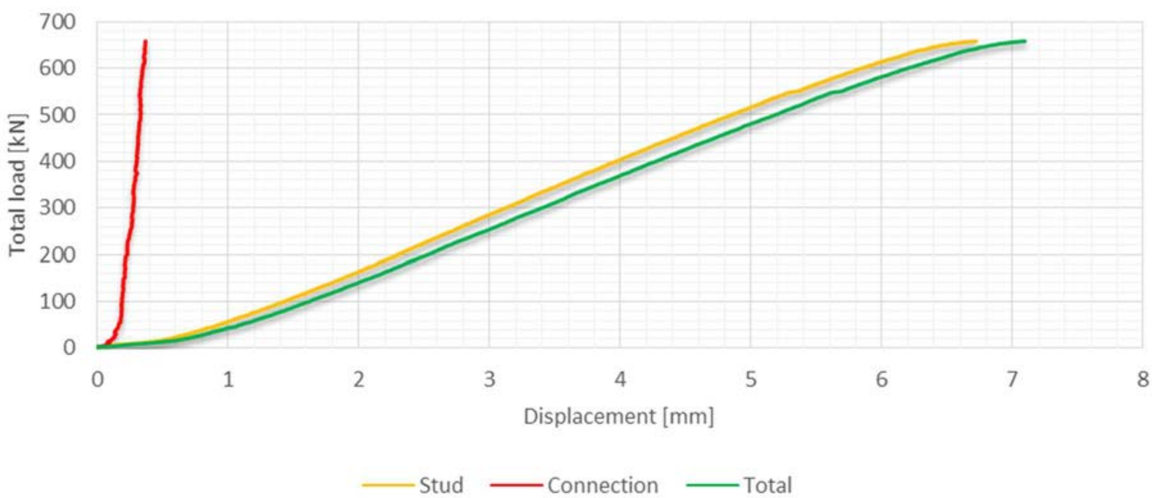


Figure 37: Test 6.1 B - Stud on Stud

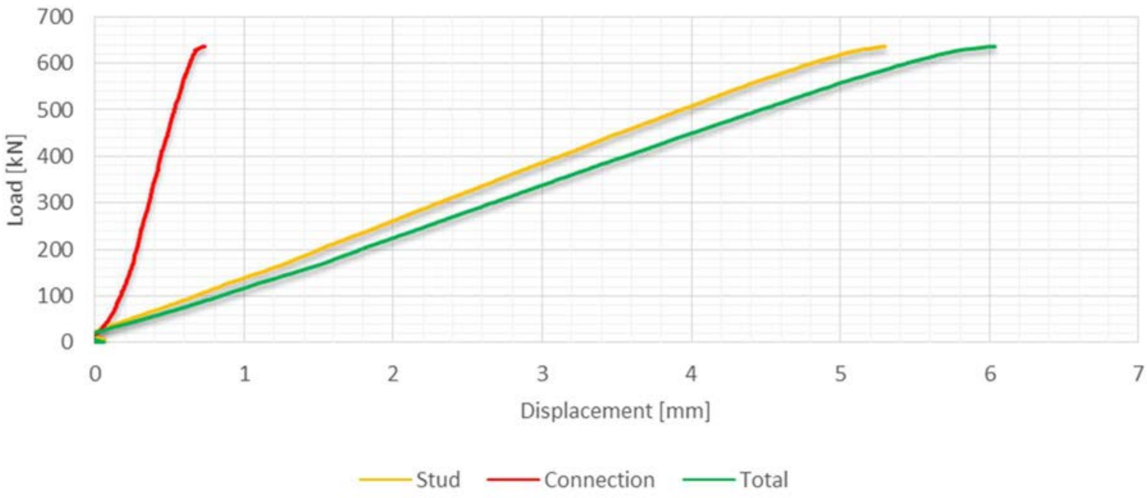


Figure 38: Test 6.2 D - Stud on Stud

Figure 39: Mid Height Buckling of Wall Frame

European Notched Wall Stud

The bearing deformation was similar to the performance found in the stud on stud tests except at a lower load capacity as the stud strength was less, refer Figures 40 and 41.

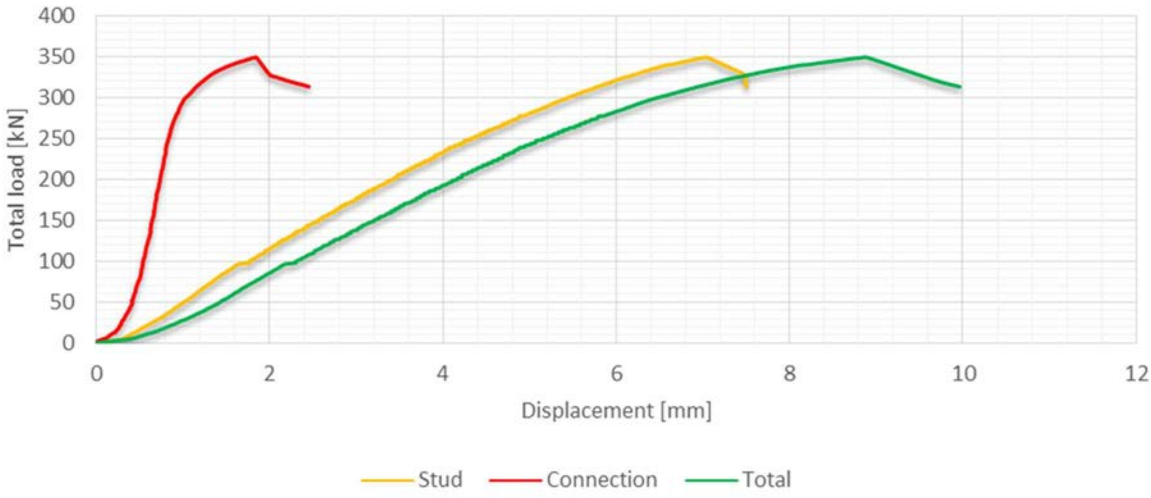


Figure 40: Test 7.1 B - European Notched Wall Frame

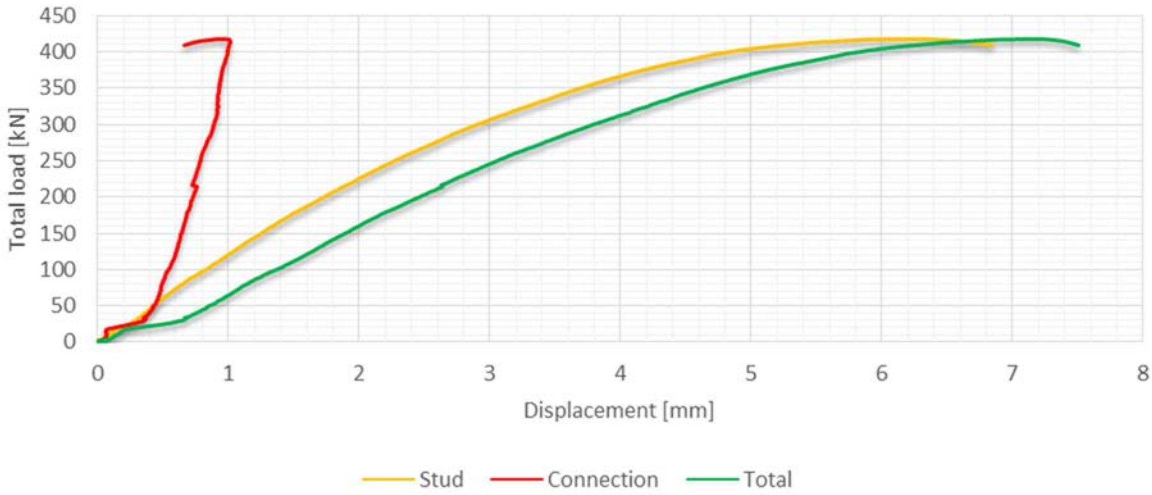


Figure 41: Test 7.2 D - European Notched Wall frame

Both of the walls ultimately failed by major axis buckling at respectively 348 kN and 417 kN. It was observed that the stud failed approximately mid-height and the failure was initiated by a location of a dominant knot cluster, refer Figure 42a. The stud ends were also observed to crush into each other with the latewood penetrating into the lower stud's early wood, Figure 42b.

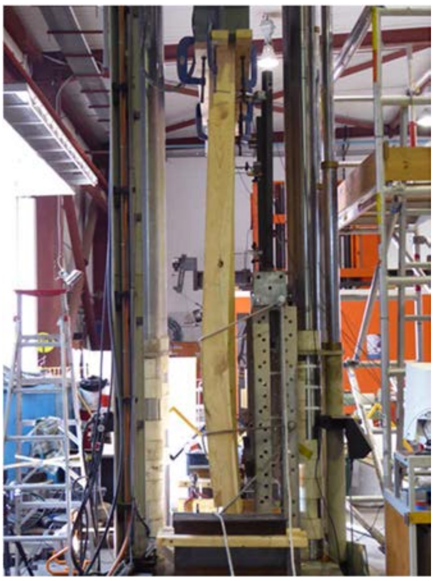


Figure 42a: Buckling initiated by Knot cluster


Figure 42b: Embedment of stud

Text for Guide

In reviewing the outcome of the research it was found that a guide devoted entirely to this subject of bearing perpendicular to grain was difficult to justify as there were still too many unknowns. One of the conclusions to the research project is that the bearing perpendicular to grain calculation method in AS1720.1 needs to be completely changed, refer to the discussion section of this report. The outcomes of most value are the load/deformation graphs for various timber species and engineered timber. Here a designer with knowledge of the wall plate being used could estimate the deformation likely from crushing in a wall framed system.

The information has been submitted to the team developing a guide on Mid-Rise Timber Framed buildings and if possible incorporated into that guide.

DISCUSSION

From the research it was evident that the best method to reduce crushing displacement in wall plates was to avoid loading the plate altogether, i.e. no perpendicular to grain crushing. This is possible when the studs in wall frames beared directly onto the end of another stud in the lower wall frame. If this wall frame configuration is not possible the next best method is to replace the wall plate element with timber that has a higher perpendicular to grain strength such as denser softwood, hardwood or even a CLT wall plates.

Reinforcing the wall plate with screws or brackets was found to offer little improvement over unreinforced options. The cost of installing screws or brackets outweighed the small increase of the performance achieved. The most cost efficient method to improve the effectiveness is to replace the entire wall plate with a better performing plate, as this method does not need any modification into the fabrication method of current wall frames.

AS1720.1 Perpendicular to Grain Values for Timber Species

It was found that even though only 5 repeat tests were carried out for each timber species the perpendicular to grain bearing capacity published in AS1720.1 incorrectly predicted their performance. For timber species with low to medium density, AS1720.1 over estimated their capacity whilst for timber with high density, AS1720.1 under estimated their performance, refer to Table 3 and Figure 43.

Table 3: Perpendicular to Grain Bearing capacity from AS1720.1 and Research

	AS 1720.1 Values			Test Values	
Timber Species	Density ADD kg/m^3	Bearing Perpendicular to Grain (MPa)		Density ADD kg/m^3	Bearing perpendicular to grain (MPa)
		Base Value	Adjusted for k7 bearing length of 45 mm		
Spotted Gum	1100	23	28.5	1169	54.2
Red Ironbark	1050	19	23.6	1078	39.7
Blackbutt	900	23	28.5	1000	32.6
Karri	900	23	28.5	880	31.7
Silvertop Stringybark	850	23	28.5	890	22.9
Flooded gum	850	19	23.6	840	21.6
Alpine Ash	650	17	21.1	600	15.0
Cypress	700	10	12.4	690	26.5
American Douglas Fir	550	13	16.1	470	9.3
NZ Radiata pine	550	10	12.4	500	10.5
MGP10 Radiata pine (S1)	550	10	12.4	450	8.6
MGP10 Radiata pine (S2)	550	10	12.4	460	10.1
MGP12 Radiata pine (S1)	550	10	12.4	523	10.2
European Spruce	460*	10	12.4	396	6.4

Note: Density from Wood in Australia, Bootle, 2005

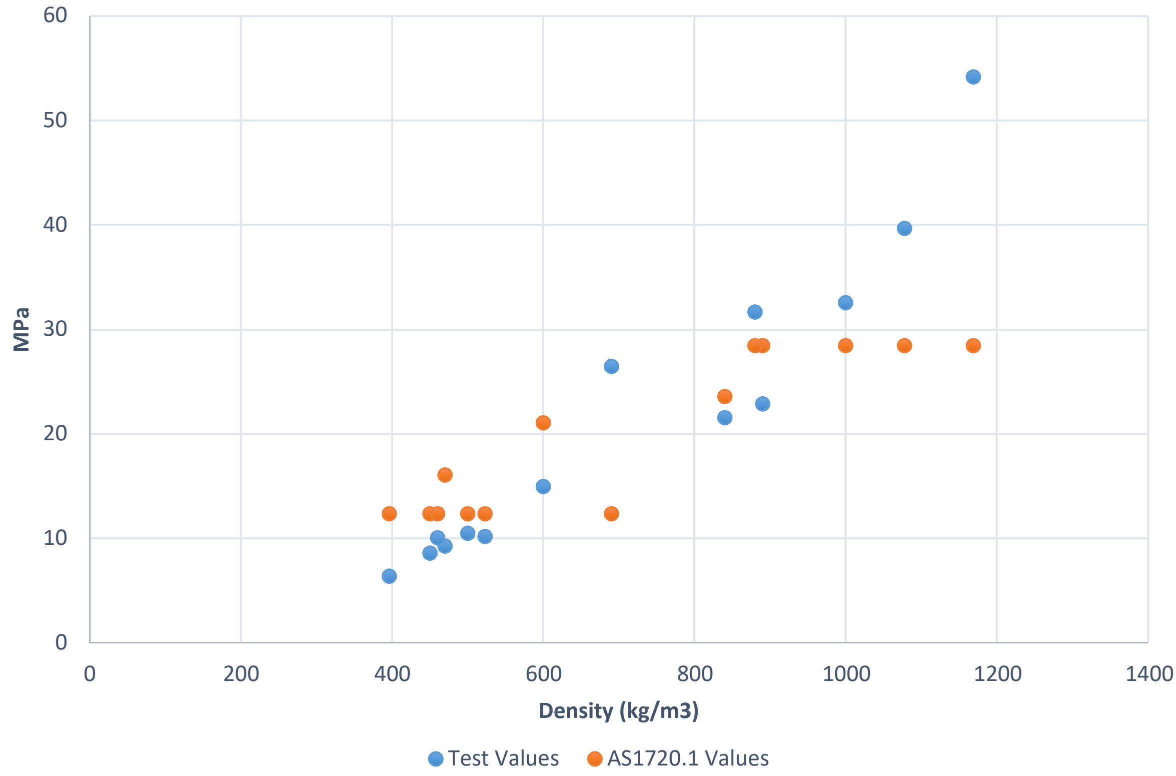


Figure 43: Perpendicular Bearing Capacity from AS1720.1 and Tests Results

It was also found that perpendicular to grain bearing capacity is more related to the timber's density than to the timber species' "strength group" or stress grade currently used in AS1720.1 to assign values, refer to Figure 44.

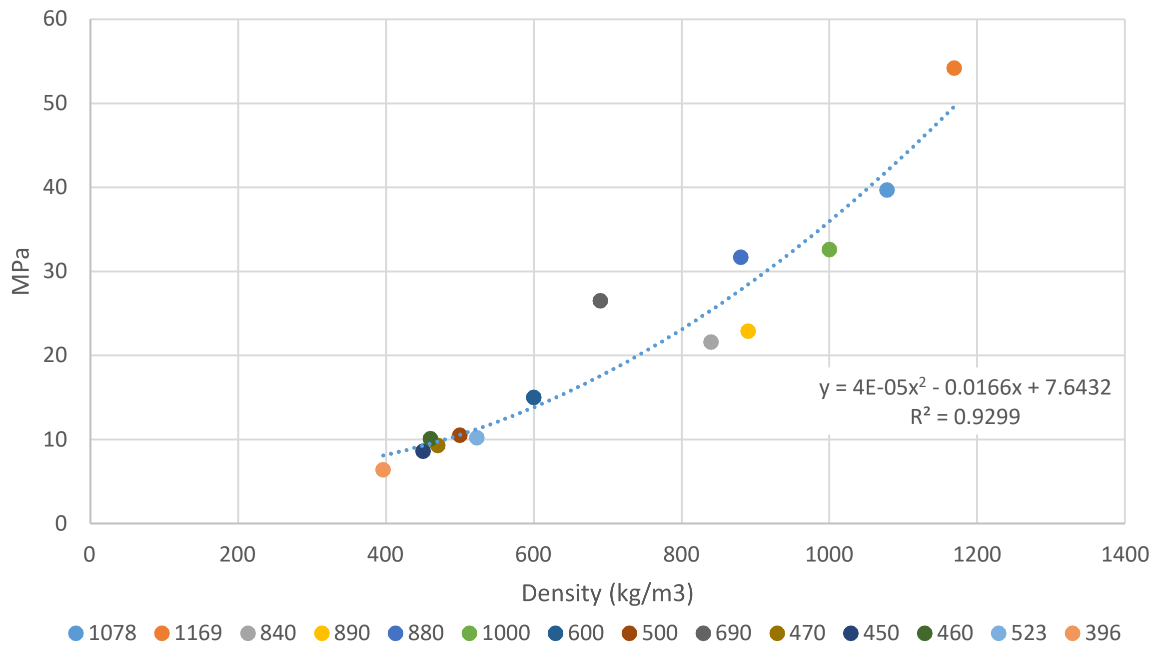


Figure 44: Bearing Capacity versus Timber Density

Recommendation 1

AS1720.1 cease providing perpendicular to grain capacities based on strength group or stress grade and base them on the timber species density

Specific reference is made to MGP grades as perpendicular to grain strength is the same value irrespective of the timber species used. It was found from the limited testing done that the capacity of low density softwoods i.e. less than 400 kg/m^3, graded to MGP10 was considerably overstated up to a factor of two.

Recommendation 2

The perpendicular to grain bearing capacity characteristic values for commonly used timber species used in construction be re-established by testing in accordance to AS/NZS 4063

From the research it was found that engineered timber had considerable variation in perpendicular to grain bearing and in some instances has a greater crushing deformation when compared to tests of the same base timber species. It was also found that the direction of loading i.e. on flat or on edge varied the result by up to a factor of two. However when comparing the tested values against the producers published values, where available, found the tested values were in line with the published values including the difference between on flat and on edge.

The issue remains that not all producers of engineered wood published their perpendicular to grain capacity and designers when faced with no information use sawn timber values resulting in an over prediction of performance. Also because most of the engineered wood is imported there are different methods to test for perpendicular to grain, particularly in Europe where the original producer's values may not be in line with the assumptions used in AS1720.1.

Recommendation 3

It is recommended that producers of Engineered Wood Products continue to publish their own values but use AS/NZS 4063 method of testing. Also AS1720.1 note that designers be advised not to use sawn timber capacities when designing the bearing capacity of engineered timbers

k7 Bearing Length Factor

The values f'_p for bearing perpendicular to grain of timber species is determined by AS/NZS 4063. The test method in AS/NZS 4063 requires a 50 mm wide plate loaded on a timber specimen in the middle of a 220 mm long piece of timber, refer to Figure 1. The characteristic value is determined as the load causes a 2.0 mm deformation into the timber specimen from an average of 30 tests.

AS1720.1 Clause 2.4.4 *Length and position of bearing* allows rectangular bearing areas located 75 mm or more from the end of a piece of timber to increase their characteristic capacity in bearing perpendicular to the grain as determined in AS1720.1 Clause 3.2.6, by the value based on the length of actual bearing, refer to Table 4.

Table 4: AS1720.1 K7 Bearing Length Factor

Length of Bearing of member	12	25	50	75	125	150 or more
Value of k7	1.75	1.4	1.2	1.15	1.1	1.0

There exists a conflict in that the value of k7 for 50 mm can be increased by a factor of 1.2 (20%) although the characteristic value is determined from this bearing length. Logically the 50 mm bearing length factor should be 1.0 not 1.2. This issue is further compounded by the characteristic value of low and medium density timber species found in the research being less than the published values. Therefore k7 bearing length factor further over predicts the capacity perpendicular to grain, making the bearing capacities for low density softwoods further from their actual values.

Ideally the k7 value for 50 mm should be a value of 1.0 to reflect the test outcome. If this was adopted it would also mean that perpendicular to grain bearing at the end of the timber element will also need addressing as the value is currently 1.0. The value at the end of a piece of timber will need to be around 20 % less as found in the research. Also the values for a bearing length greater than 150 mm need to be reassigned but to what value? This aspect was beyond the scope of the project.

Recommendation 4

That k7 bearing length be reviewed to align with how the characteristic value is determined

Strength Check versus Serviceability Check

The perpendicular to grain bearing check in AS1720.1 is currently a strength check, i.e. if the bearing pressure is greater than the bearing resistance, then bearing capacity has be exceeded. The test results in the research of full-scale wall frames showed that at ultimate load, the bearing of the studs on the wall plates did not fail in breaking but generally had excessive displacement. It was then observed that the bearing resistance behaviour changed the buckling mode of the stud, with stiffer wall plates resulting in higher stud capacity. Therefore the bearing capacity is more a serviceability issue not a strength issue.

This is confirmed in the establishment of characteristic values for perpendicular to grain bearing for different timber species where the bearing perpendicular to grain in AS/NZS4063 is the load to cause a 2.0 mm displacement. Subsequently designers are oblivious that the check within AS1720.1 for bearing is actually a check on displacement. This is unlike other serviceability checks within AS1720.1 e.g. deflection, where designers are able to determine their own deflection limits, not a predetermined value of 2.0 mm for all situations controlled by AS/NZS 4063.

For mid-rise timber framed building designers, they often find perpendicular to grain bearing capacity of wall plates dominate the sizing of studs as increase stud cross section is required to meet AS1720.1 bearing limits. Designers are further unable to determine the deformation occurring in perpendicular to grain as there is no serviceability calculation method available.

The research found that a more reliable method was to use the actual bearing resistance per timber species or wall configuration. The full scale wall systems tested found that a load per mm deformation was an output from the test. This information could be used by designers to calculate deformation for a particular timber species or wall plate configuration, refer to Table 5 and Figure 45.

Table 5: Bearing Resistance Rates kN/mm for various Wall Configurations

Description	k [kN/mm]
Stud on Stud, LVL 90 x 45	116
CLT plate	108
Cypress plate	82
Victorian Ash plate	57
MGP10 plate, reinforced with full thread screws	42
Reference wall, MGP10 plate	33.3

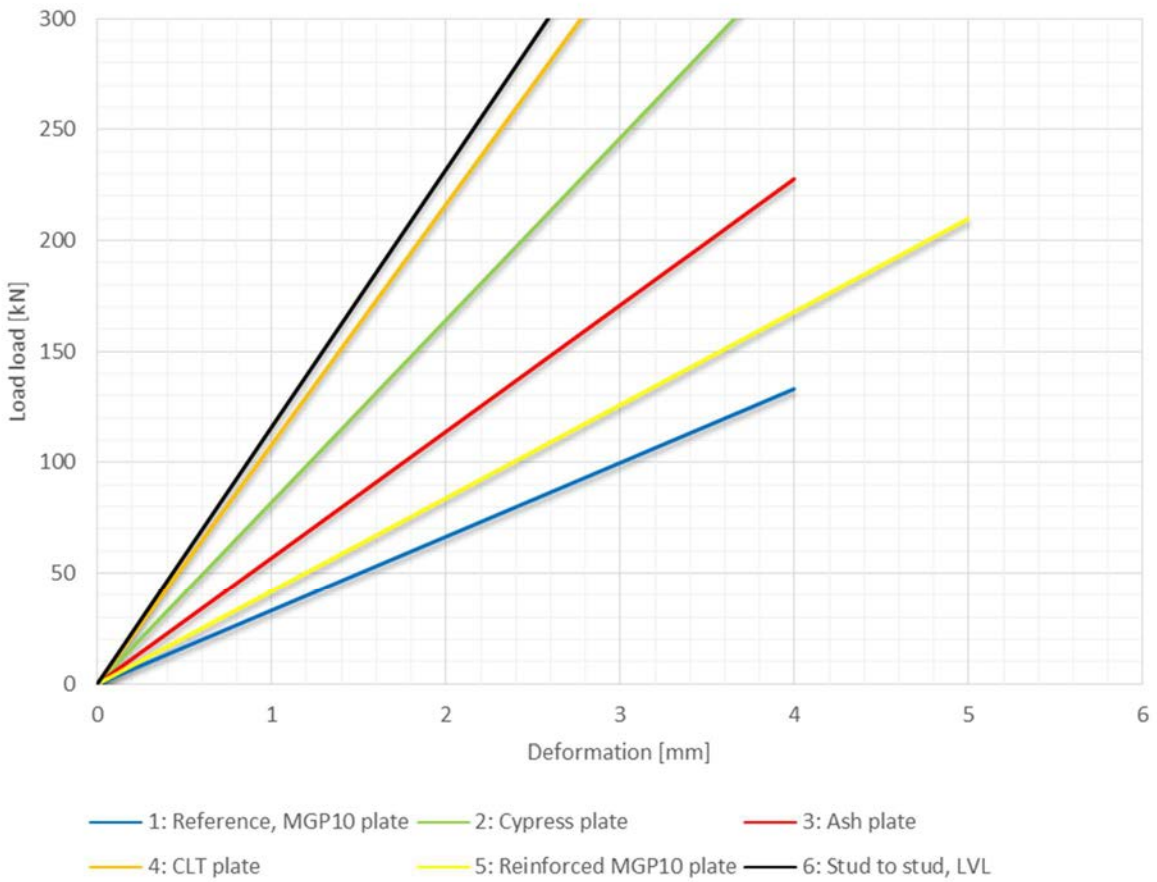


Figure 45: Bearing Resistance Rates kN/mm for various Wall Configurations

Consideration will also need to be given to addressing "edge effects" i.e. bearing length up to 150 mm. Also long bearing length, greater than 150 mm ,such as wall plates on mass timber floors will need investigating as Boughton & Hill found that k7 in this situation should be 0.5 not 1.0 as allowed in the Standard.

Recommendation 5

The AS1720.1 Perpendicular to Grain bearing check be changed form a strength check to a serviceability check

Creep

In the research it was not possible to investigate creep to any large extent as the duration of the loads was not very long. It was observed that in all cases deformation was still increasing as the duration of the load increased therefore creep behaviour was likely to occur. This parallels the results found in the desk top investigations from Martensson's[6] research where creep behaviour was observed.

As creep behaviour is well understood in timber and because the creep behaviour for bearing perpendicular to grain was found to be the same as deflection, the same creep factor for bearing perpendicular to grain displacement may also be the same as for deflection. Unfortunately the current AS1720.1 strength check for perpendicular to grain bearings does not allow the applying of the creep factor although AS1720.1 Clause 2.4.1.2 Effect on Deformation correctly states, "*For members in bending and compression and shear deformation or tensile deformation, the calculated short-term deformation shall be multiplied by the appropriate modification factor for creep (j2 or j3), as given in Table 2.4";* for perpendicular to grain a j_2 factor of 2 should be applied.

Effective Stud Length

In conducting the full-scale wall test a larger than expected range of 2.7 times of ultimate load of the wall frame system was experienced, refer Table 6. The configuration of the wall frame was identical for each test except for the wall plate being used, i.e. the same stud and fixings were used in each experiment. Furthermore, in almost all cases, major axis buckling behaviour was the cause of ultimate failure of the wall system. Therefore the only variable that differed in all the tests was the bearing of the stud onto the wall plate or lower stud in one case. The stud at the top of the wall was bearing directly onto the stiff beam from the loading rig and could be considered to be a "flat end".

Table 6: Ultimate Load for Various Wall Configurations

	Test B (kN)	Test D (kN)
Reference wall Frame MGP10 plates	240	240
Fully Threaded Screws	250	260
Cypress Wall Plates	430	400
Victorian Ash wall plates	N/A	473
CLT Wall Plates	480	450
Stud on Stud	659	636

The buckling of compressive members is calculated in AS1720.1 with the help of the Effective Length factor g_{13}. This factor aims to calculate the effective length of the compression member and is based on Euler's theory. Unlike many other international standards that use an effective length equal to the actual length of the stud, in the case of a stud wall AS 1720.1 assigns a factor of 0.9 for the calculation of studs in light timber framing, refer Table 7.

[6] Mårtensson A, Short- and Long term Deformations of Timber Structures, Lund University

Table 7: EFFECTIVE LENGTH FACTOR (g_{13}) FOR COLUMNS WITHOUT INTERMEDIATE LATERAL RESTRAINT

Conditions of end restraint	Effective length factor (g_{13})
Flat ends	0.7
Restrained at both ends in position and direction	0.7
Each end held by two bolts (substantially restrained)	0.75
One end fixed in position and direction, the other restrained in position only	0.85
Studs in light framing	0.9
Restrained at both ends in position only	1.0
Restrained at one end in position and direction and at the other end partially restrained in direction but not in position	1.5
Restrained at one end in position and direction but not restrained in either position or direction at other end	2.0

NOTE: "Flat ends" refers to perfectly flat ends bearing on flat unyielding bases.

Australian Standards has another method to calculate the effective length for house framing, i.e. limited to two storeys, and this is found in AS1720.3[7]. In this Standard the effective length is dependent on the actual stud length:

- Stud length less than 2.4 m – effective length is 0.75
- Stud length greater than 4.2 m – effective length is 1
- Stud length 2.4 m to less than 4.2 m, effective length is and equation.

$$G_{13} = 0.139\ L + 0.417$$

L = stud length

The term "flat end" given in AS1720.1 corresponds to the column standing with all the surface of its section on a very strong support, i.e. as would occur in a compression test machine. If this column is seated on a softer support it is easier for it to rotate crushing the side of the support as seen in the test series.

In the case of a standard MGP10 pine timber frame, the wall plate is usually not strong enough to limit the rotation of the column therefore performing more like a pin i.e. being restrained in position only. As the plates or systems became stiffer a more "flat end" behaviour is observed effecting the *effective lengt*h and therefore increasing the load capacity of the wall system.

The change in buckling behaviour can be observed in Figures 46 and 47. In Figure 46 the buckling behaviour was observed to be nearly flat end behaviour for both ends of the stud and had the stud buckling with the maximum deflection in the mid height of the stud.

[7] AS 1720.3:2016 Timber structures - Design criteria for timber-framed residential buildings

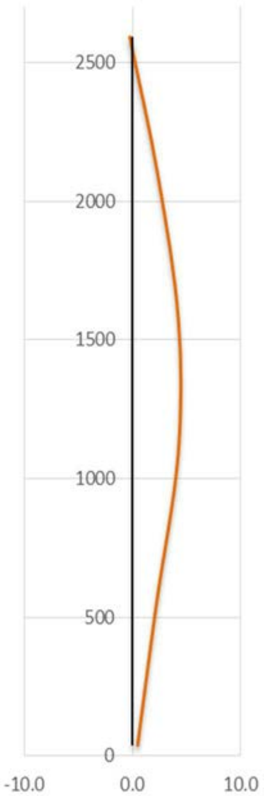


Figure 45: Horizontal movement of Middle Stud

Figure 46: Buckling shape of Configuration 6

Therefore the stiffer wall plate connection not only reduced the axial shortening but also increased the stud's ultimate compression capacity.

Recommendation 6

Further investigations are warranted to understand the contribution bearings have in reducing the effective length of a stud ultimately affecting the capacity of the wall system.

CONCLUSIONS

The aim of the project was to validate the assumption used within the Australian Standard AS1720.1 for calculating compression perpendicular to grain for common timber species and develop practical methods to reduce compression deformation.

The project was successful in demonstrating that perpendicular to grain deformation can be reduced for wall systems. It found the best method was to remove the wall plates out of the load path altogether, this being achieved by stud on stud connection. Where this is not possible replacement of the wall plate with a stiffer timber such as high density hardwood, softwood or cross laminated timber lessens this deformation. Very high density hardwoods and CLT was found to be the best method but it is recommended that further investigation be conducted on the CLT wall plate system in order to understand the splitting behaviour of CLT wall plates under ultimate loads.

It was found from the research that the method to reinforce the wall plates by screws, brackets or bearing plates did not change the bearing capacity enough to justify the expense of the fixings or labour cost to install.

The investigation also found that AS1720.1 method to assign perpendicular to grain bearing capacities for various timber species by "strength group" or stress grade over predicted low to medium density timber species whilst under predicting high density timber species. From the research it was recommended that perpendicular to grain bearing capacity be assigned by timber density.

The research also found that AS1720.1 k7 bearing length factor was incorrect as it did not match the source characteristic value determined by AS/NZS 4063 as the Standard increases the bearing capacity by 20% when it was not warranted. The research further found that the perpendicular to grain bearing strength check in AS1720.1 is misleading designers in what they were doing, ignoring that a serviceability check was actually being conducted. The research recommended that AS1720.1 method be changed to a serviceability check, for example, deflection, so that designers can limit the deformation required and also account for creep.

It was also found that the *effective length* in calculating the buckling capacity of a stud is effected considerably by the stiffness of the wall plate used. As the stiffness of the wall plate increased the *effective length* shortened considerably increasing the capacity of the stud. It is recommended that further work in this area be carried out as the current method contained within the timber engineering standard will heavily penalise wall systems that utilise stiff wall plates or stud to stud connections.

RECOMMENDATIONS

Recommendation 1
AS1720.1 cease providing perpendicular to grain capacities based on strength group or stress grade and base them on density

Recommendation 2
The perpendicular to grain bearing capacity characteristic values for commonly used timber species used in construction to be re-established by testing in accordance to AS/NZS 4063.

Recommendation 3
Producers of Engineered Wood Products continue to publish their own values but use the AS/NZS 4063 method of testing. Also AS1720.1 note that designers be advised not to use sawn timber capacities when designing the bearing capacity of engineered timbers.

Recommendation 4
The k7 bearing length be reviewed to align with how the characteristic value is determined.

Recommendation 5
The AS1720.1 Perpendicular to Grain bearing check be changed from a strength check to a serviceability check.

Recommendation 6
Further investigation is warranted to understand the contribution that bearings have in reducing the effective length of a stud which ultimately affects the capacity of the wall system.

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- Hyne Timber
- Meyer Timber
- Pryda
- MiTek
- RothoBlaas
- SPAX Pacific
- Wesbeam

Steering Committee

- Stephen Dayus – Wesbeam – Chairman
- Geoff Stringer – Hyne
- Tim Rossiter – MiTek

Timber Industry Assistance

- Craig Kay – Tillings Timber
- Geoff Boughton – TimberEd

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